

ART. IX.—*Alkali Hybrid Rocks of Port Cygnet, Tasmania.*

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## Introduction

The alkali rocks of the Port Cygnet district were first described by Twelvetrees, in a series of short papers published between 1898 and 1907, and later by Paul (1906). They were thought to be of Permian age until Skeats (1917) showed that the related porphyry dykes near Woodbridge are intrusive into the Mesozoic dolerites. Further instances of this relationship were discovered subsequently at Port Cygnet, by Reid (1922).

The rocks were known simply as felspar porphyries, on account of their strikingly porphyritic character, until Twelvetrees and Petterd (1898) attempted the difficult task of classifying them—one of the earliest petrological studies made in Tasmania. For this purpose, they examined a collection of specimens whose field relations were not always known, some of them being not in situ when collected. They divided their specimens into three groups:—

- (1) Effusive rocks—comprising hauyne-trachytes, aegirine-trachytes, melanite-trachytes, and augite-trachytes.
- (2) Intrusive rocks—comprising sanidine-augite-hauyne-aplites, and malchites (diorites).
- (3) Plutonic rocks—comprising augite-syenites, both with and without elaeolite.

The so-called "effusive" rocks, interpreted as contemporaneous lava flows in the Permian sediments exposed in the workings of the Livingstone mine, 2 miles north-east of Cygnet (Lovett) township, were discovered to be thin sills, or bedded dykes, and in a later classification (Twelvetrees, 1902), the "effusive" rocks were grouped with the "intrusive" rocks as dyke intrusions. At this time, also, Twelvetrees (1902 A) drew attention to the unusual rocks occurring at Regatta Point, on the western shore of Port Cygnet. These he interpreted as the products of the differentiation in situ of a small stock, which showed outward gradation from a core of syenite, through essexite, to a margin of the rare rock type, jacupirangite. His identifications of these rock types were confirmed by Professor Rosenbusch, of Heidelberg, to whom he submitted specimens, and later by Paul (1906), who described in detail the collection of Tasmanian igneous rocks sent to Rosenbusch by Twelvetrees, and made several chemical analyses of them. The first chemical analyses of any Port Cygnet rocks were made by McLeod and White (1899).

In 1907, Twelvetrees again reclassified the Port Cygnet rocks into two groups:—

- (1) Plutonic rocks—comprising quartz-augite-syenite (akerite), elaeolite-syenite, essexite, monchiquitic-shonkinite (monchiquitic nephelinite of Paul), and jacupirangite, all these types occurring chiefly at or near Regatta Point.
- (2) Dyke rocks—comprising nepheline-syenite-porphry (sometimes bearing hauyne), solvsbergite-porphry, mica-solvsbergite, tinguaitite, and tinguaitite-porphry.

In 1917, Skeats, describing various dykes from the Oyster Cove and Port Cygnet districts, referred to them by the simpler description of alkali-porphry.

#### PRESENT WORK.

In 1937, the author visited Port Cygnet to study in detail the supposed differentiated stock at Regatta Point. Examination of these rocks has shown that there is no differentiated stock, and that most of the unusual rocks reported by Twelvetrees and Paul, such as essexites, monchiquitic-shonkinites, and jacupirangites, are not differentiates of a syenitic magma, but hybrid rocks of very local development, formed by reaction of a potash-rich magma with a body of Mesozoic dolerite. Mapping also revealed that a single type of fine-grained alkali-porphry predominates throughout the district, and that the unusual rock types that figure so largely in previous descriptions constitute somewhat less than 1 per cent. of the total volume of igneous rocks exposed.

Twelvetrees' collections of rocks and thin sections have been dispersed, and the collection at Heidelberg, described by Paul, is not available. This, combined with the absence of any previous geological map showing the distribution of their rocks types, or even the location of the described specimens, makes it difficult to correlate them always with the descriptions that follow. The collections of the Geology Departments of the Melbourne and Sydney Universities include a number of specimens from this area, which were put at the author's disposal. These specimens were gathered in the company of Twelvetrees, but their localities are not always described precisely. They do not differ, however, in any particular from the rocks collected during the present investigation.

The first geological map of the district was made by Reid (1922), based on a reconnaissance of the area in connection with a study of the Sandfly coal measures. This map outlines the general distribution of the Tertiary igneous rocks without differentiating the types. The map accompanying this paper (fig. 2) is based upon Reid's map, the formlines, with some modifications, being taken from an unpublished map prepared by the late Dr. A. N. Lewis, of Hobart, and generously placed at my disposal by him. Reid's boundaries have been considerably altered, but the geological boundaries as now drawn are still conjectural in a number of places marked by broken boundaries in fig. 2. However, the possibility of my returning to the area to complete the field work is so remote that it is thought best to place the work on record as it now stands. The localities of analysed specimens and other specimens specifically referred to in the text are indicated by numbers, thus (81) on figs. 2 and 4.

### General Geology

The Port Cygnet district is about 30 miles south of Hobart, between the D'Entrecasteaux Channel on the east and the Huon Estuary on the west and south. It is divided centrally by the Port Cygnet, a tributary of the drowned Huon River system. The main township is Cygnet, formerly called Lovett, at the head of Port Cygnet. The area consists essentially of a broad belt of flat-lying and tilted mudstones and shales of Permian age, intruded by more or less north-south belts of Mesozoic dolerite, the more easterly dolerite masses being the more extensive (fig. 1). The alkali rocks extend from Sturges Bay and Brooks Bay, on the southern shore of the

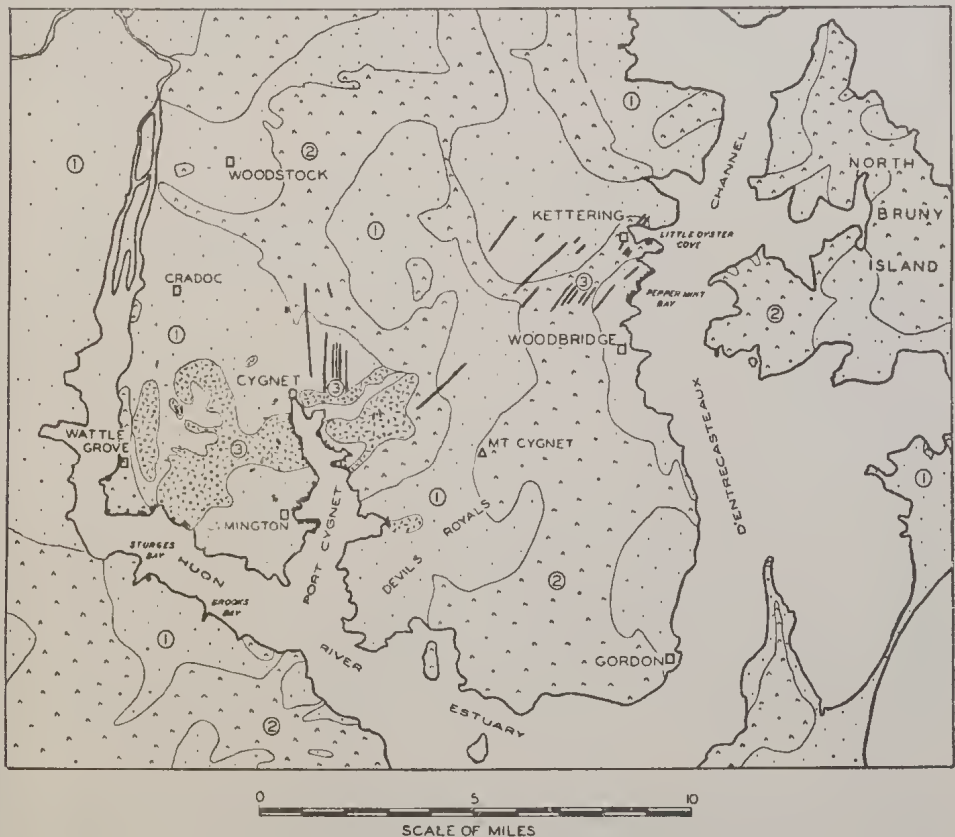


FIG. 1.—Locality map, showing the general geology of the Port Cygnet district.  
1. Permian sediments, 2. Mesozoic dolerite, 3. Alkali Porphyry and dykes.

Huon Estuary, north-eastwards to Oyster Cove on the shore of D'Entrecasteaux Channel, their continuity being interrupted by the belts of dolerite that lie east of Mt. Cygnet and the Devils Royals.

The alkali rocks outcrop chiefly in the form of a partly unroofed stock of syenite-porphry, which is intrusive into both the Permian sediments and the Mesozoic dolerite. As is shown in Fig. 2, it occupies the greater part of the squarish peninsula to the south-west of Cygnet township, between the drowned valleys forming the Huon Estuary and the Port Cygnet Estuary, and extends to Toby's Hill and Nicholl's Hill to the north-east and east of the township, respectively. The irregular shapes of the outcrops and their discordant contacts suggest that the roof of the stock consists of a series of small steep-sided cupolas.

Associated with the stock are numerous dykes of syenite-porphry of varying composition. These intrude both the stock, the sedimentary rocks marginal to it, and the dolerites. Similar dykes outcrop on the southern shore of the Huon Estuary, at Sturges Bay and Brooks Bay; and to the north-east of Cygnet, on the eastern side of the belts of dolerite, a number of identical syenite-porphry dykes and small sills occur in the vicinity of Woodbridge and Kettering, and along the shore of D'Entrecasteaux Channel from Little Oyster Cove to Peppermint Bay.

The alkali rocks have induced only slight contact alteration of the Permian sediments and the dolerites. The sediments are frequently silicified or indurated for a few feet from the margins of the larger intrusions, and the dolerite shows slight uralitization. Only at Regatta Point has dolerite been found which has been intensely altered by the porphyries. At this locality, a dyke-like body of dolerite was invaded by a potash-rich magma, presumably a differentiate from the syenite-porphry stock, and reaction between the potash-rich magma and the dolerite has given rise to a variety of unusual hybrid rocks.

## The Alkali Rocks

### THE SYENITE-PORPHYRY (BANATITE) INTRUSION.

The prevailing rock type in the Port Cygnet district is a relatively fine-grained syenite-porphry. When fresh, it is light-grey to buff coloured, and consists of closely-crowded squarish phenocrysts of plagioclase, about 1 to 2 mm. long, with more sparsely-distributed larger white to pinkish phenocrysts of orthoclase, about 5 mm. across, and numerous phenocrysts of hornblende, ranging from 0.5 to 3.0 mm. in length, and generally smaller than the feldspars, set in a felspathic ground-mass.

The plagioclase phenocrysts usually appear idiomorphic in thin section, and are zoned. Some crystals show oscillatory zoning. The zoning is accompanied by both lamellar and Carlsbad twinning. The plagioclase is optically positive, and has a maximum extinction angle in the symmetrical zone at right angles to (010) of about 25° in the cores of the zoned crystals, and about 20° in the marginal zones. Cleavage flakes show a refractive index of 1.550 in one direction, and a somewhat higher index in the direction at right angles. These optical properties indicate that the plagioclase is andesine, about Ab<sub>55</sub> in the cores of the crystals, and Ab<sub>65</sub> at the margins.

The orthoclase occurs as fewer, but much larger, idiomorphic crystals, which frequently include several small idiomorphic crystals of plagioclase, together with small crystals of hornblende or pyroxene. Only one or two

such orthoclase crystals are present per square inch of thin sections. The included plagioclase crystals are smaller than the plagioclase crystals occurring free in the ground-mass, suggesting that the orthoclase and plagioclase crystallized simultaneously. Moreover, there is an occasional parallel intergrowth of orthoclase and plagioclase. Much of the orthoclase is untwinned, but some crystals show simple twinning. Some crystals are cloudy owing to slight kaolinization, and there is a tendency for the kaolinization to develop zonally, which suggests that the crystals show a zonal change in composition from core to margin like the plagioclase. Cleavage fragments show refractive indices ranging from a little below to a little above 1.525, and the crystals are optically negative, with  $2V$  about  $15^\circ$ , so that the feldspar is perhaps best described as a variety of sanidine. A partial analysis of a composite hand-picked sample reveals that it has a composition approaching  $Or_{33}Ab_{47}An_{22}$  (Table 3). The proportions of  $NaAlSi_3O_8$  and  $CaAl_2Si_2O_8$  indicated are probably high, owing to unavoidable contamination of the soda-sanidine with small inclusions of plagioclase (andesine). Unusual though this composition is, it appears from Alling's (1921, Fig. 19) diagram to be a possible composition for a high temperature feldspar. Mackinen's diagrams, as reproduced by Alling (1936, p. 72), suggest that feldspars of the sanidine-barbierite series (delta-anorthoclase series of Alling) can carry more  $CaAl_2Si_2O_8$  in solid solution than other alkali feldspars; and that at temperatures of about  $1000^\circ C$ . feldspar of a composition  $Or_{35}Ab_{45}An_{20}$  could crystallize simultaneously with a plagioclase of composition about  $Or_{20}Ab_{40}An_{40}$ , i.e., a potash-rich andesine.

Accompanying the feldspars in each section there are a few rounded and embayed phenocrysts of quartz, about 0.5 to 1.0 mm. across.

The proportion of ferromagnesian minerals varies from specimen to specimen. They include both hornblende and pyroxene, which occur as prismatic phenocrysts about 0.5 mm. long, with occasional prisms up to 3.0 mm. long. Hornblende is invariably present, but pyroxene occurs only in occasional specimens. The pyroxene was the earlier of the two to form, since some phenocrysts consist of a core of pyroxene with a margin of hornblende. The pyroxene is green to colourless, and non-pleochroic. It has an extinction angle of about  $45^\circ$  on the prism face, and has a  $2V$  greater than  $45^\circ$ , so that it is an augite. It is probably similar in composition to the analysed pyroxene whose composition is given in Table 6, Analysis No. 1. The analysed pyroxene was concentrated from a syenitic dyke (sanidine-porphyr) at the mouth of Deep Bay, on the eastern side of the Port Cygnet Estuary. The hornblende is pleochroic, from brown to yellow-green, and can be presumed to have a composition close to that of the hornblende analysis shown in Table 6, Analysis No. 4. The analysed hornblende was taken from a dyke rock at Little Oyster Cove, practically identical in appearance with the porphyries under discussion.

Other minerals present in the porphyries are magnetite, sphene, and apatite, which occur as crystals up to 0.3 mm. long. The ground-mass consists essentially of orthoclase in small squarish crystals about 0.02 mm. across, so that it has an orthophyric texture. A little interstitial quartz accompanies the orthoclase.

In thin sections, the porphyries closely resemble a dacite or toscanite. Their syenitic affinities are more apparent from hand specimens, and from their chemical composition. Two chemical analyses were made, one of a specimen from the saddle between Lymington and Wattle Grove, near the centre of the Port Cygnet Peninsula (54), and

one from the cliff outcrop at Petchey's Bay, near the south-west corner of the peninsula (72). The first specimen contains both pyroxene and hornblende; the second contains only hornblende, and the hornblende is partly replaced by ragged areas of calcite, and a little epidote. These analyses are set out in Table 1, Analyses Nos. 1 and 2, together with analyses showing the average composition of akerite and quartz-monzonite, the two rock types that most closely resemble the syenite-porphyrries in chemical composition. The resemblance is closer to the akerite than to the quartz-monzonite, but in addition to the textural difference, the porphyries differ mineralogically from akerite in that hornblende rather than pyroxene is the dominant ferromagnesian mineral in them. It is possible that the porphyry is chilled capping or border phase that passes into akerite in depth, since akerite has been reported to occur near Lymington and at Regatta Point (Twelvetrees, 1907, p. 9), but too much significance should not be attached to these reports.

The Lymington occurrence is described by Skeats (1917, p. 157) as a dyke-like body of akerite, occurring at a point  $1\frac{1}{2}$  miles up the Forester Rivulet, on the back road from Lymington to Mt. Mary. This area is now under cultivation, and the akerite body was not located during the present investigation. Two thin sections, labelled as from this locality ("Back Road") are included, however, among those loaned from the Geology Department, University of Sydney. One of these (S.10001) appears to be a true akerite. It consists of large phenocrysts of sanidine, up to 1 cm. long, in a coarse ground-mass of clear plagioclase, cloudy orthoclase, greenish pyroxene, and interstitial quartz. Other minerals present are sphene, apatite, and magnetite. The individual feldspar crystals of the ground-mass tend to be idiomorphic, and are from 0.5 to 1.0 mm. long. The plagioclase, which predominates, is strongly zoned, the cores consisting of basic andesine, while the margins consist of oligoclase. The orthoclase associated with it contains a little ex-solution microperthite. In the hand specimen, this rock does not appear notably different from the typical syenite-porphyry; and in thin section it suggests a porphyry from which the fine ground-mass has been excluded, leaving only the phenocrysts crowded together. It closely resembles some of the minor dyke rocks described below as syenite-aplites, at Regatta Point and elsewhere.

The second section (S.10004) is a medium-grained holo-crystalline syenite, consisting essentially of orthoclase showing abundant ex-solution microperthite, and aegirine augite, with a little interstitial quartz, and some biotite, apatite, and sphene. The orthoclase grains tend to be about 0.5 mm. across, but in patches are considerably smaller. The aegirine-augite crystals enclose cores of colourless augite, and are generally prismatic in form. This rock also has its counterparts among the syenite-aplites of Regatta Point.

Akerite is also recorded to occur at Regatta Point (Twelvetrees, 1907). No such outcrop was observed during this investigation, but two sections labelled "akerite" from this locality in the collection of the University of Sydney (S.10002 and 10003) closely resemble some of the syenite-aplite dykes that occur in the zone of hybrid rocks at Regatta Point. No. 10002 consists essentially of squarish crystals of plagioclase from 1.0 to 2.0 mm. across, sometimes cloudy at the centre, and orthoclase, with lesser amounts of quartz, augite, hornblende, magnetite, and apatite. The orthoclase is chiefly interstitial to the plagioclase, or forms rims around the plagioclase crystals, which are strongly zoned. The central zones of the plagioclase crystals consist of basic andesine, and the marginal zones are oligoclase. Hornblende is much more abundant than the pyroxene, which is colourless,

and the magnetite crystals are rimmed with granules of sphene. No. 10003 is similar, but contains more orthoclase and quartz. The orthoclase contains ex-solution micropertthite intergrowths, and the plagioclase is restricted to inclusions in large orthoclase crystals. It is commonly altered to sericitic or to zeolitic material.

There is a close chemical resemblance between the syenite-porphry and the "banatite" that forms the uppermost zone of the differentiated laccolith of Mt. Dromedary, near Milton, in New South Wales (I. A. Brown, 1926), as can be seen from the analyses in Table 1. Holmes' (1927) definition of a "banatite" as "an orthoclase-bearing quartz diorite" fits well with the general mineralogical character of the Cygnet porphyry, so that it seems better described as a form of banatite, rather than of akerite. Unfortunately, Johannsen (1938, p. 384) recommends that the term "banatite" be disused, on the grounds that it is vaguely defined and obsolescent.

If the resemblance to the Mt. Dromedary rock is more than superficial, then it is possible that the deeper-lying rocks in the Cygnet stock may be of monzonitic or even shonkinitic character.

#### DYKE ROCKS.

Numerous dykes are exposed in the cliff sections of the Cygnet Peninsula, and in particular along both shores of the Port Cygnet Estuary. Dykes are also exposed in various road cuttings, and to a lesser extent elsewhere; and in view of the thick soil cover that prevails over much of the area, it may be assumed that many more dykes occur than are visible. The dykes intrude the syenite-porphry stock, the Permian sediments, and the Mesozoic dolerites, and include a variety of rock types. The sequence of intrusion of the different types of dyke is not altogether clear.

#### SYENITE-PORPHYRY DYKES.

Dykes of syenite-porphry that are practically identical in composition with the syenite-porphry of the main intrusion are found at intervals around its margin. At Shag Point and Copper Alley (fig. 2), and along the inland roads leading from Lymington to Wattle Grove and Petchey's Bay, they can be seen intruded into Permian sediments. Close to Cygnet jetty one such dyke can be seen invading the dolerite exposed in the low cliffs (38).

Along the eastern shore of the Port Cygnet Estuary, syenite-porphry dykes from 2 to 40 feet wide occur in profusion in the cliffs from north of Crooked Tree Point as far as the Green Point jetty, intruding Permian sediments.

Occasional dykes of this type, intruded into Mesozoic dolerite, are exposed along the coast between Wattle Grove and the south-western corner of the Peninsula, along the Huon Estuary.

A number of dykes and occasional small sills of similar syenite-porphry occur in the vicinity of Woodbridge and Kettering. They are exposed along the shore of the D'Entrecasteaux Channel at Little Oyster Cove, Perch Bay, and Peppermint Bay, and in road cuttings. They have been described by Skeats (1917), who showed that they intrude both the Permian sediments and the Mesozoic dolerite. Hornblende is the only ferromagnesian mineral present in these rocks, and it occasionally occurs as clots several centimetres across. An analysis of the hornblende in one of the dykes in Little Oyster Cove is shown in Table 6, Analysis No. 4.

## HAUYNE-SANIDINE-GARNET-PORPHYRY DYKES.

This striking rock, known locally as "magpie rock," occurs in a series of dykes and plugs extending northwards from Toby's Hill, north and north-east of Cygnet township (fig. 2). The Livingstone gold mine was situated on the contact of one such dyke, on the north-west flank of Livingstone Hill, which is a spur of Toby's Hill. The rock consists of numerous white to glassy tablets of sanidine, up to 20.0 mm. long by 3.0 mm. thick, together with crystals of black garnet, 1 to 2.0 mm. across, and less numerous black prisms of hornblende or pyroxene, up to 3 mm. by 1 mm., set in a grey felspathic ground-mass. The sanidine phenocrysts generally show parallel alignment with the strike of the dyke.

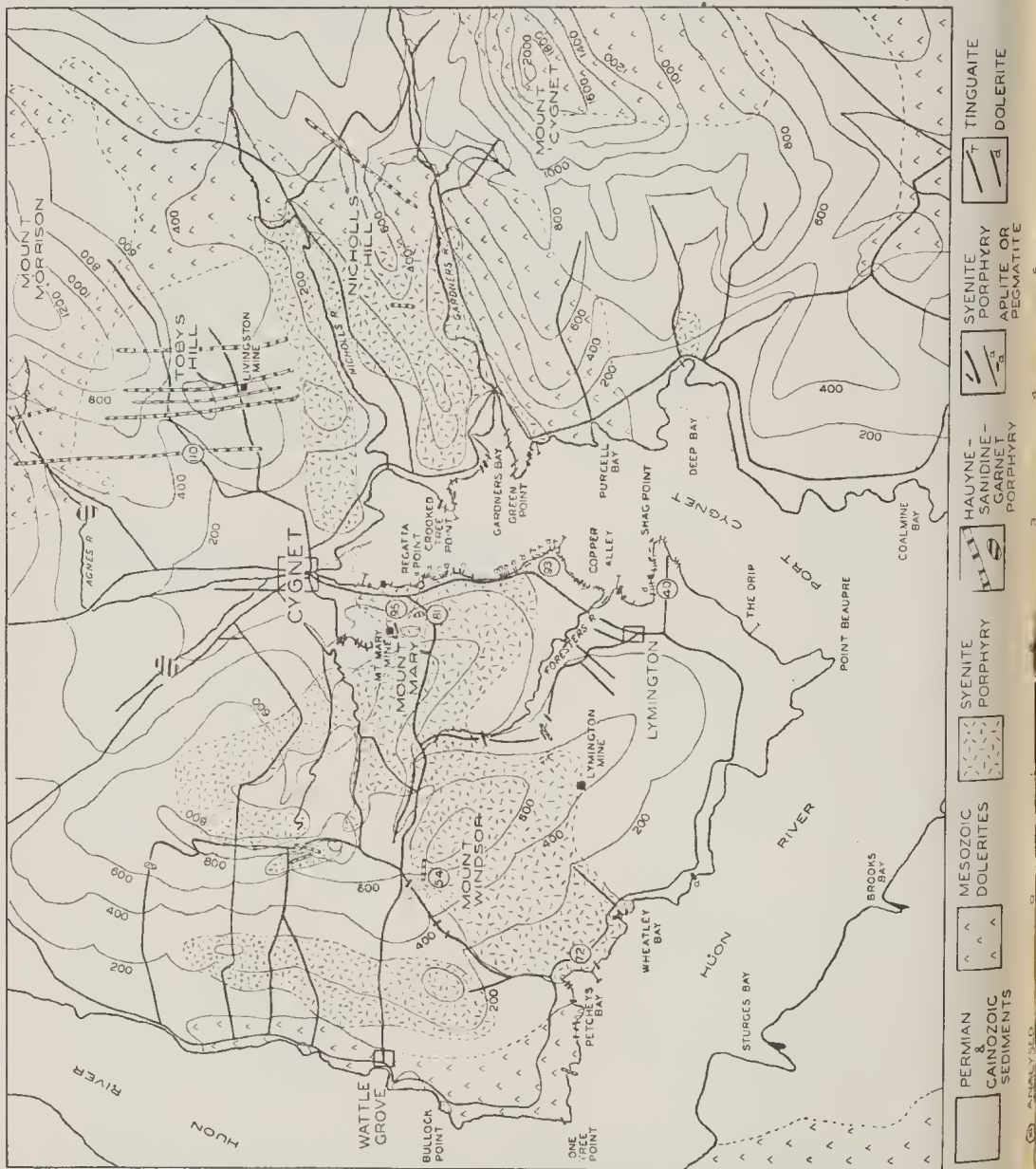


FIG. 2.—Geological sketch map of Port Cygnet. [Geological boundaries modified after A. M. Reid; form lines modified after A. N. Lewis.]



Thin sections show that, in addition to the sanidine phenocrysts, there are smaller phenocrysts of zoned plagioclase, with almost straight extinction, indicating that it is oligoclase, about  $Ab_{80}$ , and numerous microphenocrysts of more or less altered hauyne, up to 0.3 in width, but generally smaller. The hauyne occurs as inclusions in the sanidine phenocrysts, and free in the ground-mass. It is identified by its isotropic character, its consistent hexagonal form, and its refractive index, which is below that of sanidine. It is commonly altered completely to a fibrous zeolite substance, presumably natrolite. More rarely it has altered to analcite, or has been preserved unaltered. In some sections the hauyne crystals are flecked with specks of bluish-black dust. Some of the hauyne crystals are altered to a micaceous aggregate. Rosenbusch suggested that these crystals represented altered nepheline, but their invariable hexagonal outline favours hauyne rather than nepheline.

The garnet is a brown melanite, as is proved by a chemical analysis of a small sample extracted from one specimen (Table 6, Analysis No. 8). It occurs as strongly zoned, idiomorphic crystals, about 0.5 mm. across, frequently forming clusters (Plate IV., fig. 1), and sometimes intergrown with hornblende or pyroxene.

The hornblende occurs commonly in small prisms which are pleochroic from deep-brown to deep-green. An analysis of a small purified sample indicates that it is an iron-rich variety of hornblende, with a low magnesia content (Table 6, Analysis No. 5), and relatively rich in potash and soda. In these respects, it is comparable with the hornblendes found in alkali-syenites and related rocks.

The pyroxene in some sections is aegirine, strongly pleochroic from green to yellow, and with a small extinction angle. In other specimens it is aegirine-augite, often with a core of colourless augite, in every respect similar to the pyroxene found in the syenite-porphyr.

In addition, there are occasional coarse crystals of sphene and apatite, though these minerals are not as abundant as in other rocks of the district.

The ground-mass has a pilotaxitic to trachytic texture, and consists essentially of orthoclase microlites, with fine shreds of hornblende, minute flakes of yellow-brown biotite, granules of brown garnet, and granules of magnetite. Some of the minute hornblende shreds show a blue pleochroism, suggestive of riebeckite.

A chemical analysis of a typical rock (110) is shown in Table 2, Analysis No. 2. The analysis, with its high contents of potash, soda, and lime, and its under-saturated character with respect to silica, emphasizes the unusual character of the rock.

On the western shore of the Port Cygnet Estuary, immediately south of the jetty at the northern headland of Copper Alley (fig. 2), there occur two dykes about 10 feet wide, identical in appearance with this rock. One or other of these dykes appears to be the source of the rock described by Rosenbusch as a "fine-grained elaeolite-syenite" (Twelvetrees, 1901, p. 2; 1902, p. 296). The dyke rock from "south of the Regatta Ground," described by Rosenbusch as a "garnetiferous mica solvsbergite" (Twelvetrees, 1901, p. 3), and analysed by Paul (1906) (Table 2, Analysis A), was probably from this locality. It is also probable that one of these dykes is the "garnet trachyte" analysed by McLeod and White (1899). The analysis is quoted in Table 2, Analysis B.

A closely similar rock is exposed in a quarry just north of the road leading off from Regatta Point across the peninsula to Wattle Grove (81). Exposures are poor, but the rock is apparently a dyke intruding the

syenite-porphry, or else it is a deeper-lying portion of the main intrusion. The sanidine phenocrysts are light-grey, and approach more closely the colour of the ground-mass than those of the dyke rocks just described. They lack pronounced parallel alignment, and the ground-mass is somewhat coarser-grained, with an orthophyric texture. In addition, the rock contains more hornblende, and less garnet. The hornblende frequently encloses remnants of pyroxene, and occasional grains have a core of colourless augite. The garnet is finer-grained than in the Toby's Hill dykes, and does not show such well-developed zoning. It is generally intergrown with the hornblende, sometimes in glomeroporphyritic clots. Magnetite, and occasional crystals of sphene, are generally associated with the garnet-hornblende clots; and the association of these minerals is such as to suggest that all four are products of the breakdown of augite. Occasional coarse crystals of sphene and apatite are also distributed through the ground-mass. Some hornblende occurs in the ground-mass, where it is patchily distributed in small granules and prisms, and granules of magnetite are uniformly distributed through the ground-mass.

Hauyne microphenocrysts are present more abundantly than in the Toby's Hill rocks. The hauyne is generally altered to a zeolitic substance, whether included in the sanidine phenocrysts or free in the ground-mass (Plate IV., fig. 2). The small plagioclase phenocrysts are corroded, and armoured with a rim of orthoclase.

A chemical analysis of this rock, Table 2, Analysis No. 1, shows that it is a little more acid, and contains rather less soda than the analysed rock from Toby's Hill, but is otherwise similar.

Dykes that closely resemble this rock, except that they apparently contain no hauyne, have been found at Petchey's Bay, and at One Tree Point.

#### SANIDINE-GARNET-PORPHYRY DYKES.

Closely related to the "magpie rocks" are dykes of a still coarser sanidine-garnet-porphry, known locally as "biscuit rock," in which the abundant sanidine phenocrysts commonly measure 3.0 cm. x 2.0 cm. x 0.5 cm. These large phenocrysts, which are white to buff-coloured, are set in a grey feldspathic matrix that is spotted with black phenocrysts of garnet about 1 to 2 mm. across. Dykes of this rock have been found intruding the syenite-porphry stock near the centre of the Cygnet Peninsula (66), and at Toby's Hill and Nicholl's Hill. Similar dykes are exposed in cuttings through Permian sediments along the Lymington to Wattle Grove road, at points 1 mile and 2 miles from Lymington (fig. 2).

The exposed rock at all these localities is somewhat weathered, so that it is not possible to establish the presence of hauyne in the rock with certainty. Thin sections show the presence of a number of more or less hexagonal areas, now completely altered to micaceous substances. These areas occur both in the trachytic ground-mass, and as inclusions in the sanidine phenocrysts; and they closely resemble in form and disposition the hauyne crystals of the "magpie rock." Some of the micaceous patches in the ground-mass may represent altered ferromagnesian minerals, since ferromagnesian minerals other than the melanite garnet appear to be absent from the "biscuit rock." The chief point of difference from the "magpie rock," however, is the smaller proportion of plagioclase present. Moreover, partial analyses of the coarse sanidine phenocrysts of the two rocks indicate that the sanidine in the "biscuit rock" is richer in potash than the sanidine in the "magpie rock" (Table 3), and has a composition approximating to  $Or_{78}Ab_{16}An_6$ .

## SANIDINE-BIOTITE-PORPHYRY DYKE.

Near the Mt. Mary mine occurs a dyke rock which contains rather sparsely-distributed megaphenocrysts of sanidine, comparable in size and appearance with those of the "biscuit rock." They are somewhat sericitized, and are set in a ground-mass of plagioclase laths and intersertal orthoclase, studded with ragged laths and patches of biotite, up to 1.0 mm. long, and with idiomorphic crystals of magnetite of about the same dimensions. Numerous small flakes of biotite and muscovite occur in the interstices of the orthoclase laths. The larger flakes of biotite are often composite clusters of numerous minute flakes, so arranged as to preserve the crystal outlines of a pre-existing hornblende. The biotite and magnetite appear to be derived from the reaction of the hornblende with the potash-rich residue that formed the ground-mass. The plagioclase laths of the ground-mass show straight extinction, so that they are oligoclase, about  $Ab_{80}$ . A little apatite and sphene are present as accessories, but there is no garnet.

## SANIDINE-PORPHYRY DYKES (TRACHYTES).

Narrow dykes that closely resemble trachytes occur intruding the metamorphosed dolerite at Regatta Point (1, 2), and at the mouth of Deep Bay. The dykes at Regatta Point consist of a number of small simply-twinned crystals of soda-sanidine, up to 2 mm. long, with microphenocrysts of augite, showing some alteration to hornblende, and an occasional garnet, set in a trachytic ground-mass of orthoclase laths and uniformly distributed minute crystals of garnet, prisms of green hornblende, and granules of magnetite. The sanidine crystals all contain abundant micropertthite, and it seems probable, from their situation in the zone of thermal metamorphism, that the unmixing of the micropertthite resulted from the reheating of the metastable soda-sanidine solid solution. A further indication that these dykes probably predate the metamorphism and hybridization of the dolerite is provided by a specimen (12) from the zone of hybridization, whose outcrop was largely hidden by sand, but which appears in thin section to be a somewhat altered and recrystallized trachytic dyke.

## SANIDINE-TINGUAITE DYKES.

Immediately north of the jetty at the northern headland of Copper Alley, two coarsely porphyritic dykes outcrop on the beach. They consist of large white to buff phenocrysts of sanidine, set in a dense green ground-mass. The dykes are each about 3 feet wide, and have narrow chilled margins against the Permian sediments which they intrude, and which are indurated at the contacts. The sanidine phenocrysts tend to be aligned parallel to the long axes of the dykes. They measure about 2.0 cm. x 1.0 cm. x 0.1 cm., and are somewhat clouded. The cloudy areas are restricted to areas of ex-solution micropertthite that are commonly developed in the central parts of the crystals. Such micropertthite is absent from the marginal parts of the crystals, which are clear, and the perthitic core is often differentiated from the clear margin by a distinct zonal structure. The micropertthite shows lamellar twinning, with a symmetrical extinction angle of about  $5^\circ$ , and it has refractive indices which straddle that of the enclosing sanidine, so that it consists of albite-oligoclase, about  $Ab_{85}$ . It lies in the cleavage direction of the sanidine, elongated parallel to the prism faces. The sanidine crystals also contain small inclusions of apatite and needles of aegirine, and occasionally microphenocrysts of aegirine and melanite garnet. The aegirine crystals are generally zoned, and some have a core of colourless augite. Some contain small inclusions of garnet. The extreme margins of the sanidine crystals are often impregnated to a depth of

about 0.1 mm., with minute needles of aegirine, all lying with their long axes more or less parallel to the crystal boundary. A partial analysis of the sanidine from the more southerly dyke (93) shows that, like the coarse sanidine crystals in the other dyke rocks, it has a considerable soda content (Table 3). The calculated composition of the sanidine is  $Or_{57}Ab_{20}An_{14}$ .

Accompanying the sanidine phenocrysts are much smaller microphenocrysts of orthoclase and aegirine. The aegirine, which tends to occur in clots, is often altered to a secondary white mica.

The ground-mass has a tinguaitic texture. It consists of a felted mass of aegirine needles about 0.1 mm. x 0.01 mm., intergrown with microcrystalline orthoclase and a little oligoclase. The feldspars tend to be lath-shaped, and in places show flow structure. Some nepheline may occur in the ground-mass, but it has not been identified with certainty, although Rosenbusch claims to have detected it (Twelvetrees, 1901, p. 3). Dispersed through the ground-mass are occasional lens-shaped areas which consist of relatively coarse laths of oligoclase intergrown with orthoclase, and equally large prisms of aegirine. In some of these areas there are grains of andalusite, strongly pleochroic from rose-pink to colourless. In addition, there are occasional crystals of apatite and sphene.

To the north of these two dykes is a third green dyke, which lacks the coarse sanidine phenocrysts. A thin section reveals an occasional phenocryst of sanidine and of aegirine, with a core of colourless augite, in a microcrystalline ground-mass of aegirine needles and orthoclase laths, showing pronounced parallel orientation. Distributed through the ground-mass are numerous small areas of a colourless mineral with low birefringence, which would appear to be nepheline, except that it appears biaxial and optically positive.

A further tinguaitic dyke (95) outcrops on the hillside above the Mt. Mary mine. This rock is identical with those just described, except that it contains fewer coarse phenocrysts of sanidine; and that in the coarser patches of the ground-mass, the place of andalusite is taken by a colourless mineral that resembles scapolite. It has a higher refractive index than the plates of feldspar with which it is intergrown, is uniaxial and negative, with straight extinction parallel to the prismatic cleavage, and has a moderately high birefringence. Crystals showing an optical figure have low polarization colours, and are commonly crowded with inclusions in their central parts. It may be noted that Daly (1933, p. 527) records the occurrence of primary scapolite in nepheline syenite from the Hastings-Haliburton district of Ontario, and Knight (1906, p. 286) has recorded it in the ground-mass of a leucite-bearing tinguaitic from Spotted Fawn Creek, in the Yukon.

Twelvetrees (1898) originally referred to these coarsely porphyritic rocks as "aegirine trachytes". Rosenbusch suggested that this name should be amended to tinguaitic-porphry, or better, solvsbergite-porphry (Twelvetrees, 1901, p. 3). They have also been called "tinguaitic-solvsbergite-porphry" (Skeats, 1917). Chemical analyses were made of the more southerly porphyritic dyke (93) immediately north of Copper Alley jetty, and of the dyke (95) above the Mt. Mary mine (Table 2, Analyses Nos. 3 and 4). The analyses confirm the tinguaitic-like character of the rocks, but reveal that they are unusually rich in potash and poor in soda for typical tinguaites (Table 2, Analysis C). They are too poor in silica and soda, and too rich in lime and potash, to be regarded as solvsbergites or their equivalents (Table 3, Analysis E). An approximate match is provided by a tinguaitic with sanidine phenocrysts from the Bearpaw Mountains of Montana (Weed and Pirsson, 1896) (Table 3, Analysis D), but this rock

contains definite nepheline and sodalite in the ground-mass, whereas the soda in the Port Cygnet rocks occurs chiefly as a constituent of the felspar and the aegirine. The term "sanidine-tinguaite" has been adopted here for the Cygnet rocks as more descriptive than tinguaite-porphyry.

#### SYENITE-APLITE AND SYENITE-PEGMATITE DYKES.

Buff-coloured dykes, veins, and schlieren of syenite-aplite and syenite-pegmatite occur at a number of points along the beach and cliff section in the vicinity of Regatta Point, and occasional dykes of this character outcrop in the cliffs near Petchey's Bay, and along the eastern shore of the Port Cygnet Estuary. The dykes are up to 3 feet wide, and in exceptional cases 10 feet wide, and can be divided into two groups, those with typical aplitic texture, and those consisting of coarse plates of sanidine, up to 3.0 cm. long, closely packed in a finer felspathic matrix. The former are referred to here as syenite-aplites, and the latter as syenite-pegmatites. Their late origin is proved by the fact that they intrude the whole group of hybrid rocks exposed at Regatta Point.

The aplites, though apparently uniform in the hand specimen, are somewhat variable in composition. Some (6a) consist essentially of interlocking equigranular grains of cloudy orthoclase, from 0.5 to 1.0 mm. across. Associated with the orthoclase are occasional grains of oligoclase, and rather more numerous grains of quartz. The orthoclase crystals frequently contain some micropertthitic albite in their central parts, though not in their margins. The oligoclase crystals are generally smaller and more prismatic than the orthoclase crystals. The quartz tends to be interstitial. In addition, there is a little brown biotite, a grain or more of magnetite, or of an altered ferro-magnesian mineral, and an occasional grain of apatite and zircon. One specimen contained a number of small irregular-shaped grains of blue corundum, with which was associated a little muscovite.

In some of the aplites (17), the plagioclase occurs as rather larger zoned crystals, and about equals the orthoclase in amount. The cores of the zoned crystals are a basic andesine, while the margins consist of oligoclase. The marginal oligoclase is generally cloudy, but the cores of andesine are clear, or are stained yellow along fractures. The small amount of quartz in such rocks is interstitial. Coarse crystals of sphene, up to 0.3 mm. in length, are dispersed through these rocks, together with occasional prisms of aegirine-augite, or colourless augite, the latter generally included in crystals of plagioclase. Some of the aegirine-augite crystals have a core of colourless augite. The ferromagnesian minerals are in places altered to chloritic substances, or to limonite, and the coarser ferro-magnesian crystals are somewhat corroded. Rocks of this type (17) are identical with the rocks labelled "akerite, from Regatta Point", in the collection of the Sydney University Geology Department (S.10002, S.10003); and they bear a general resemblance to the syenite-porphyry.

The syenite-pegmatites (25, 26, 31) consist of abundant coarse tablets of sanidine, set in a ground-mass of coarse orthoclase plates, numerous coarse grains of magnetite, and a little green pyroxene, together with a small amount of interstitial muscovite and occasional coarse crystals of sphene. Much of the felspar is cloudy, and shows slight alteration to sericite or muscovite. The coarse phenocrysts of sanidine contain patches of ex-solution micropertthite, consisting of albite showing lamellar twinning, but the ground-mass orthoclase is free of such perthite, and there is practically no plagioclase associated with it, and very little quartz in the interstices. Some of the coarse sanidine crystals show isolated broad twin lamellae, which is perhaps the result of parallel growth of crystals. One

such dyke contained a proportion of ferromagnesian minerals, but they are so largely altered to indeterminate chloritic substances that the original minerals cannot be identified.

A chemical analysis of a typical pegmatite (25) gave the composition shown in Table 2, Analysis No. 5. The analysis emphasises the fact that the rock is essentially felspar, and indicates that the sanidine in this rock, as in the others, contains a relatively high proportion of soda.

#### GARNET-ORTHOCLASITE DYKES.

Occasional dykes of garnet-orthoclase rock, about 1 ft. wide, are exposed in the beach section at Regatta Point. These rocks closely resemble the syenite-aplite dykes, especially when weathered, but differ from them in that they contain a notable amount of brown melanite garnet. They are slightly younger than the aplites, because instances were noted where a garnet-orthoclase dyke (28) cut and displaced a syenite-aplite dyke.

In the hand specimen, they are fine-grained buff to pink rocks consisting of an occasional phenocryst of sanidine in an equigranular ground-mass of felspar and dark ferromagnesian minerals. Thin sections (19) show that the rock consists of occasional phenocrysts of sanidine micropertite, up to 1.0 cm. x 0.5 cm., in a ground-mass of orthoclase micropertite, melanite-garnet and aegirine augite, in which the individual grains are about 0.5 mm. across. The pyroxene is generally prismatic, and commonly consists of a core of colourless augite surrounded by a rim of deep green aegirine-augite. The garnet and the pyroxene tend to occur in clots together, in association with coarse crystals of sphene. The garnet and the aegirine-augite are in places intimately intergrown, and it seems possible that they are products of the reaction of the magma prior to complete crystallization, with some pre-existing mineral, either augite or hornblende. Other minerals present, in small amounts, are brown biotite and apatite.

Some of the garnet-orthoclase dykes (28) carry green hornblende as well as aegirine-augite, and numerous small grains of magnetite. In places biotite and garnet, intimately associated, form fringes about remnants of the hornblende, being clearly derived from its reaction with the potash-rich residual magma that formed the ground-mass.

A chemical analysis of a garnet-orthoclase (19) that carried only pyroxene with the garnet, is shown in Table 2, Analysis 6. The rock is distinctly richer in lime than the syenite-pegmatite, with a little more soda, and proportionately less potash. It is also distinctly richer in phosphorus. When allowance is made for the greater content of ferromagnesian in this rock, it is seen that the felspar is generally similar to that of the aplites and pegmatites.

#### COMPOSITION OF THE FELSPAR PHENOCRYSTS.

In all these alkali rocks, with the exception of the tinguaites, phenocrysts of plagioclase and sanidine are found side by side, and from their association appear to have crystallized simultaneously. Partial analyses were made of hand-picked samples of the sanidine phenocrysts in several of the rock types, and these, together with the calculated compositions of the phenocrysts are set out in Table 3. The sanidines in the tinguaites and in the hauyne-sanidine-garnet-porphry dykes are closely similar in composition, and are distinctly richer in potash than the sanidine phenocrysts in the syenite-porphry intrusion, and presumably in the corresponding syenite-porphry dykes. The felspars in the syenite-pegmatite appear to

be still more potassic, assuming that the potash and soda in the rock analysis (Table 2, Analysis No. 5) reflects the composition of the feldspar, while the sanidine phenocrysts in the "biscuit" rocks (sanidine-garnet-porphyrries) are still more potassic. The age relationships of the dyke rocks to one another is not clear, but the general impression is gained that there has been a more or less progressive increase in the  $\text{KA1Si}_3\text{O}_8$  content of the sanidine as differentiation has progressed. This impression is strengthened by the common development of microperthite in the core of the sanidine crystals, and its absence from the marginal zones of such crystals. Alling's (1936, p. 72) diagrams indicate that with slow cooling, unmixing of solid solutions of albite and orthoclase (barbierite and sanidine) takes place to an increasing degree. It may be assumed, therefore, that the cores of the sanidine crystals, containing microperthite, crystallized at higher temperatures, and were more soda-rich than the marginal zones of the crystals, and that on cooling to the temperature at which the marginal zones crystallized, the soda-rich cores unmixed. The marginal zones, though solid solutions, were poorer in soda, and so more stable. There is, therefore, good evidence of pronounced fractional crystallization in the development of the feldspars.

Parallel with the enrichment of the sanidine in  $\text{KA1Si}_3\text{O}_8$  there was a progressive enrichment of the associated plagioclase phenocrysts in  $\text{NaAlSi}_3\text{O}_8$ , which is revealed by the changing extinction angles of these crystals, both within individual zoned crystals, and from rock to rock. The simultaneous changes in composition of the two series of feldspars is indicated diagrammatically in fig. 3, in which the  $\text{KA1Si}_3\text{O}_8$  content of the plagioclase is assumed from Alling's data. The limits of the immiscibility gap between Or and An, and between Or and Ab are taken from his three-dimensional diagram for the system Or-Ab-An (Alling, 1936).

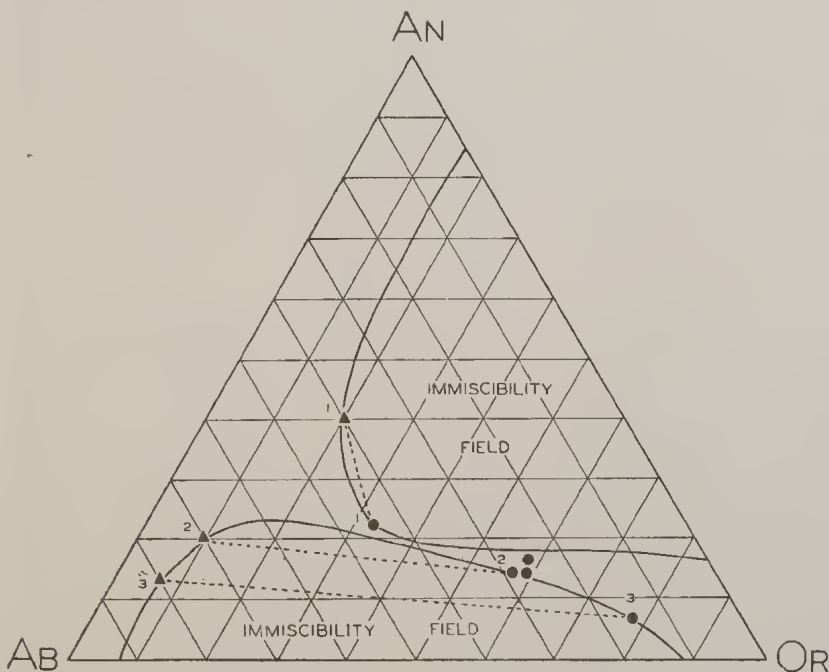


FIG. 3.—Diagram to show progressive changes in composition of the porphyritic feldspars during differentiation. 1. Syenite porphyry. 2. Hauyne-sanidine-garnet-porphyry, sanidine-tinguaite. 3. Sanidine-garnet-porphyry.

## ORIGIN OF THE GARNET.

The garnet in potash-rich dyke rocks is a typical melanite (Table 6, Analysis No. 8) such as characterises some varieties of highly alkalic rock. It is a primary reaction mineral, and appears to have originated from a reaction of earlier formed augite or hornblende with the residual potassic magma that forms the ground-mass of the rocks. The ferromagnesian minerals, whether augite or hornblende, appear to have persisted in existence until a relatively low temperature, so that when they became unstable and reacted with the potassic magma, the lime in them was unable to crystallize as plagioclase. Some proportion of it was accommodated in the sodic plagioclase crystallizing at the time the ferromagnesian became unstable, and some was accommodated in the sanidine, but the amount of lime that could be accommodated in these minerals was limited by the temperature of the magma, and was decreasing with further fall in temperature. The magma, however, was saturated with respect to alumina, so that the lime-garnet molecule became a substitute for the higher temperature lime-plagioclase molecule, and portion of the iron from the ferromagnesian minerals was also included in the garnet. The magnesia from the ferromagnesian mineral tended to combine with the potash of the magma to form biotite.

This process, of the reaction of ferromagnesian minerals with potash-rich fluid, after becoming unstable at a relatively low temperature, with the subsequent formation of melanite garnet and biotite, can be followed in detail in the hybrid rocks next to be described. In these rocks the process is seen in exaggerated form, because the hybridization involves the incorporation of a considerable proportion of ferromagnesian minerals directly into a potash-rich rest-magma.

McLeod and White (1899) described the occurrence of a garnet of most unusual composition (Table 6, Analysis B) from a "garnet-trachyte" dyke south of Regatta Point, and proposed the name "johnstonotite" for it. The locality of this dyke was not given with exactitude, but it appears to have been one of the hauyne-sanidine-garnet-porphry dykes immediately south of the jetty on the northern headland of Copper Alley. The uniform appearance of the garnet in this rock and in all the rocks examined raises doubt as to whether the sample of garnet analysed by McLeod and White was pure. Its high manganese content contrasts strongly with the low manganese content of all the analysed rocks other than this dyke (Table 2, Analysis B).

## HORNBLLENDE.

The analyses of the hornblende from the syenite-porphry dyke at Little Oyster Cove, and from the presumably younger hauyne-sanidine-garnet-porphry dyke on Toby's Hill, (Table 6, Analyses Nos. 4 and 5) suggests that there was a tendency for the iron and lime contents of the ferromagnesian minerals to increase relative to the magnesium content as differentiation progressed.

**The Hybrid Rocks of Regatta Point**

A belt of hybrid rocks, formed from the reaction of a potash-rich syenitic magma with a body of earlier intruded dolerite, is exposed in the beach and cliff section, extending southwards from the Cygnet jetty for about 800 yd., past Regatta Point (fig. 4). The least altered dolerite is at the northern end of the section, close to the jetty. The shape of the dolerite body is not clear from the exposures, but it appears to have been a moderately large dyke, trending oblique to the cliff line.



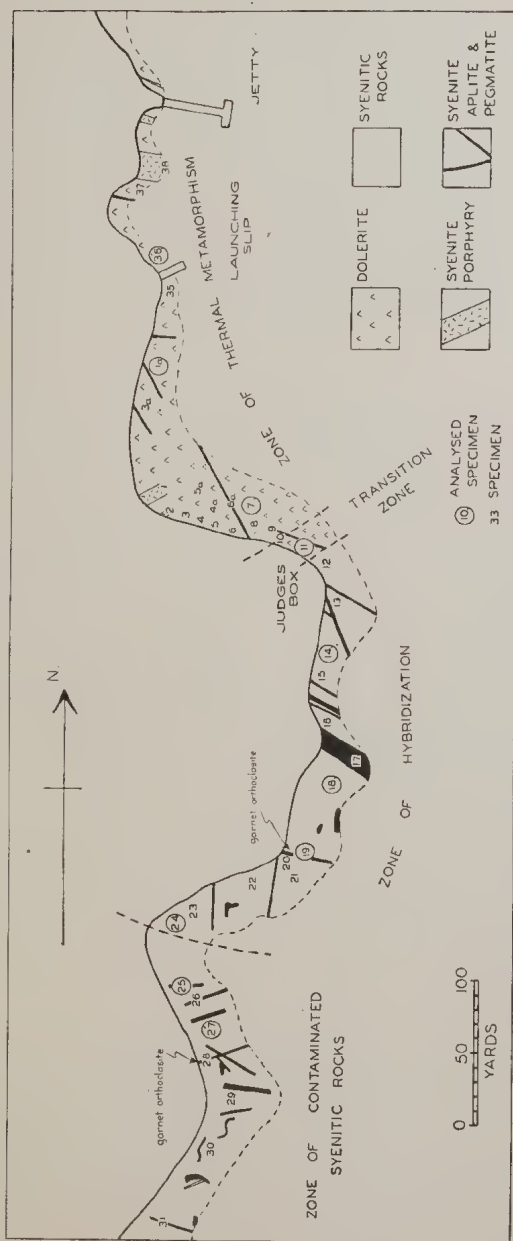


FIG. 4.—Map showing the distribution of hybridized rocks at Regatta Point.

The rock exposures can be divided into four sections of unequal length, which can be distinguished in the field, and correspond to the appearance or disappearance of various minerals that mark stages in the process of hybridization. The first section, which extends for about 200 yards south from the jetty, nearly to Regatta Point, consists of dolerite that has been altered chiefly by contact metamorphism, with a more or less complete transformation of the pyroxene of the dolerite to hornblende and magnetite. A little potash and silica appear to have been introduced during the metamorphism, but the change in chemical composition of the rock as a whole throughout this section is slight, and the rock still preserves its doleritic texture, and its dark colour. At the northern end of the section,

the dolerite is traversed by a dyke of syenite-porphry and two sanidine-porphry (trachyte) dykes. These dykes were intruded before the hybridization, because they appear to have suffered thermal metamorphism. At the southern end of the section there are also several narrow dykes of syenite-aplite and syenite-pegmatite intruding the dolerite.

The second section is only about 50 yards long, and is marked by the breakdown of the plagioclase of the dolerite, which results in the disappearance of the doleritic texture from the rock. This was accompanied by a transformation of the secondary hornblende to colourless augite, and by the introduction of potash and perhaps silica, in increasing amounts. The rock, though dark, has a granular, speckled appearance in hand specimen.

The third section, which extends round from the face of Regatta Point to the head of the embayment on its southern side, a distance of about 200 yards, consists of true hybrid rocks, rich in both lime and potash. In these rocks, the augite, formed in the stage of reaction equivalent to that of the narrow transition zone, has reacted more or less completely with the potash-rich magma, to form lime-iron garnet (melanite) and biotite, while any titania has been precipitated as coarse crystals of sphene. The greatest variation in rock types is found in this section. The rocks can be divided into three groups: (1) those as rich or richer in lime than the dolerite, (2) those poorer in lime than the dolerite, and grading into syenite, and (3) dyke rocks, consisting of syenite-aplite, syenite-pegmatite, and occasionally, garnet-orthoclase, which are younger than the hybrid rocks. The various types of hybrid rock show no regular distribution but occur in irregular patches, and schlieren, and show rapid transition from one to another.

At the southern end of this section, the hybrid rocks grade into a fourth section, consisting of a contaminated syenitic rock, which is cut by numerous narrow dykes of syenite-aplite and syenite-pegmatite, with an occasional dyke of garnet-orthoclase. This rock differs but little from the potash-rich, lime-poor rocks of the hybrid zone, and is not described separately.

#### THE DOLERITE.

Where least affected by the syenitic magma, the dolerite (36) consists essentially of basic plagioclase (labradorite, about  $Ab_{45}$ ), and pyroxene, with a small amount of granophyricly intergrown quartz and alkali feldspar, probably orthoclase, in view of the relatively high potash content of the rock (Table 4, Analysis No. 1), in the interstices of the plagioclase laths. Two pyroxenes are present, generally closely associated or intergrown, and, as is characteristic of the Mesozoic dolerites in Tasmania (Edwards, 1942), one is an augite with  $2V$  greater than 45 degrees, while the other is a nearly uniaxial pigeonite. Both occur as crystals up to 2.0 mm. x 0.5 mm., and show prominent sahlite striations in a direction making an angle of 10 degrees with the prismatic cleavage. In some sections, they tend to ophitic relationship with the plagioclase, which occurs as stumpy, unoriented laths generally about 0.25 mm. x 0.05 mm., with occasional coarser platy crystals.

The margins of the pyroxene grains are frequently choked with magnetite dust, and generally show some alteration to green hornblende. In some specimens (36), this alteration is relatively slight (Plate IV., fig. 5), in others (1a) the zone of hornblende is as wide as the core of unaltered pyroxene, but the chemical composition of the rocks shows little difference (Table 4, Analyses Nos. 1 and 2). The hornblende in the rock

is derived solely from the breakdown of the pyroxenes under the conditions of contact metamorphism. It is pleochroic with X = pale yellow, Y = yellowish-green, Z = deep green.

The original magnetite of the dolerite occurs as sparse grains up to 0.25 mm. x 0.25 mm. It is generally surrounded by a reaction rim of minute flakes of biotite, which tend to grow columnar fashion, normal to the surface of the magnetite grain. The biotite is pleochroic from straw yellow to deep brown. Such secondary biotite is developed only from the original coarse magnetite, and does not occur with the magnetite dust in the margins of the pyroxene. Such biotite fringes around magnetite grains are not normal to the dolerite, and appear to be a product of reactions induced by the contact metamorphism.

Quartz occurs in small amounts, but even so is present in unusual amounts for typical dolerite, and it seems possible that some of it has been introduced from the syenitic magma, together with the orthoclase that forms microgranophyric intergrowths with it.

Chemical analyses of the little altered dolerite (36) (Table 4, Analysis No. 1), and of its composite pyroxene (Table 6, Analysis No. 3) show that the rock is a considerably differentiated phase of the Mesozoic dolerites that are so widespread in this and other parts of Tasmania. The analyses show that it differs from described variations of the dolerites in that it contains almost twice as much MgO and several per cent. less  $Al_2O_3$  than any previously analysed Tasmanian dolerite containing only 9.5% CaO. This indicates that it has an unusually high content of pyroxene for the stage of differentiation corresponding to its CaO content, and to the relatively iron-rich character of its pyroxene. It has been postulated, from a study of the large dyke-like mass of dolerite of Gunning's Sugarloaf, in the Midlands district of Tasmania (Edwards, 1942, pp. 474, 604), that such rocks are to be expected at depths unspecified in dyke masses that have undergone differentiation after emplacement, but the Regatta Point dolerite may not have originated in this way.

A narrow dyke of unaltered dolerite (40) intruded into the Permian sediments on the south side of Copper Alley about a mile south of Regatta Point (fig. 2) shows a comparable richness in MgO relative to CaO (Table 4, Analysis No. 5). This dyke is only 2 feet wide, so that it could not have undergone differentiation to such a degree after its emplacement. It provides, therefore, the first recognized instance in Tasmania of intrusion of dolerite magma either after it had undergone differentiation, or else when it was in process of differentiating. The dolerite at Regatta Point, which appears to be a somewhat larger dyke, though not remotely comparable in size with the dyke-like mass forming Gunning's Sugarloaf, also probably underwent differentiation prior to its emplacement. Under such conditions, it is possible that differential movement of the already formed crystals and of the still fluid portion of the magma (filter press action) may have contributed to its unusual composition, and to that of the Copper Alley dyke.

From Twelvetrees' (1902A) description of the distribution of the various rock types at Regatta Point, one would conclude that the metamorphosed dolerite corresponded to his so-called jacupirangite. Comparison of the analyses of the dolerite with those of jacupirangite (Table 4, Analyses A, B) show how unlike the two rock types are. It is apparent, however, from the descriptions of the rock given by Rosenbusch (Twelvetrees, 1902A), and by Paul (1906) that the so-called "jacupirangite" consisted chiefly of augite, nepheline and orthoclase, and as indicated later, was a variety of 1. brid. The volume of such basic hybrid rocks must have

been very small—limited in fact to a few hand specimens—for careful search failed to reveal any mass of comparable rock. It seems possible that Twelvetrees confused the two rocks, and regarded the specimen described by Rosenbusch as representative of the dolerite, because he clearly regarded the thermally metamorphosed dolerite as "essexite" and as an intermediate stage of the differentiation of the syenite into jacupirangite. Otherwise, it is remarkable that he made no reference to the dolerite as such.

#### THE ZONE OF THERMAL METAMORPHISM.

This zone extends from the Cygnet jetty to about half-way along the northern side of Regatta Point (fig. 4). Throughout it the plagioclase of the dolerite remains practically unaltered, and preserves the doleritic texture of the rock. The pyroxene and magnetite, however, are more or less completely altered to hornblende and biotite, respectively.

The alteration of the pyroxene crystals begins with the precipitation of minute granules of magnetite "dust" in the margins of the crystals, and the development there of minute prisms and granules of green hornblende. As the change progresses, the hornblende spreads to the cores of the pyroxene crystals, along cleavages, and along the sahlitic striations. Simultaneously, the individual hornblende granules grow together to form coarser crystals, so that in the intermediate stage of the change, a pyroxene crystal has been converted more or less completely to a group of four or five small crystals of hornblende, generally containing numerous inclusions of magnetite. The magnetite granules show a similar tendency to grow together into larger grains, but in some crystals they begin to alter to minute flakes of biotite. In the final stage of the alteration (7A), an original pyroxene crystal is replaced by a single large crystal of hornblende, somewhat ragged at the margin, and often with a narrow fringe of minute hornblende prisms that have not been absorbed into the main crystal (Plate IV., fig. 6). Such coarse crystals of hornblende usually include scattered grains of magnetite, but ultimately they clear themselves of such inclusions. In some hornblende crystals, the original cloud of magnetite "dust" is converted into a cloud of minute flakes of biotite. These subsequently grow together to form rather coarser crystals of biotite that remain intergrown with the hornblende, or migrate to its margin.

The biotite flakes rimming the original coarse magnetic crystals undergo a similar process of growth into a few large flakes, though these rarely attain the size of the hornblende crystals. Where the original magnetite contained titania, presumably as intergrown ilmenite, the titania is precipitated as crystals of sphene, some of which are crowded with minute flakes of biotite. One instance was observed of a rim of sphene enclosing a grain of magnetite.

In a number of places the coalescence of the early-formed minute prisms of hornblende and flakes of biotite to form coarse crystals has been prevented by the introduction into the rock of alkali feldspar, apparently orthoclase. The orthoclase crystallized in the areas of altering pyroxene, as a mosaic of small allotrioblastic grains with highly crenulate margins, and as they grew, these grains caught up the small grains of hornblende and biotite as inclusions, or else pushed them into the grain boundaries of the orthoclase mosaic, so that a cloud of ferromagnesian granules dispersed through a mosaic of alkali feldspar crystals marks the former presence of a large crystal of pyroxene. Such areas of alkali feldspar and clouds of dispersed granules of hornblende and biotite are generally associated with patches of microgranophyre, which represent either original interstitial

orthoclase recrystallized with silica set free by the alteration of pyroxene to hornblende, or else introduced quartz and orthoclase derived from the syenitic magma. An analysis of the hornblende (Table 6, Analysis No. 6) shows that it has much the same silica content as the original pyroxene (Table 6, Analysis No. 3), so that it seems unlikely that the silica was derived from the change of pyroxene to hornblende. However, if the quartz and orthoclase were introduced, the amount introduced must have been small, because an analysis of altered dolerite (7A) in which the pyroxene is completely altered to coarse hornblende (Table 4, Analysis No. 43) shows very little difference in these respects from the analyses of the least altered rock (Table 4, Analyses Nos. 1, 2). It is to be noted, however, that these analyses contain slightly more potash than is normally found in the Tasmanian dolerites and are relatively rich in  $\text{SiO}_2$ . All of these rocks may, therefore, contain a small amount of introduced potash, and probably quartz; and it is noticeable throughout this zone that the alteration of the pyroxene is always more advanced in sections that contain an abundance of microgranophyre than in sections in which it is more or less absent. Moreover, in some sections the plagioclase crystals have been somewhat invaded by patches of microgranophyre, or fractures in the plagioclase crystals are filled with orthoclase veinlets that connect patches of granophyre with one another or with areas of orthoclase crystals. Some such veinlets cross several adjacent plagioclase crystals.

The ferromagnesian in these altered dolerites also show some evidence of mobility. In one section the rock is traversed by a veinlet, 0.1–0.2 mm. wide, of small colourless pyroxene crystals, with some associated sphene and pyrite. The pyroxene gives place, along the length of the veinlet, to fine-grained orthoclase and quartz. In other sections, veinlets of hornblende fill fractures and cleavages in plagioclase crystals, the veinlets in some instances being connected with large crystals of hornblende.

These rocks in which the pyroxene is more or less completely altered to hornblende, correspond to the "essexite" of Twelvetrees (1907) and Paul (1906, pp. 280–283)—"a dark dioritic-looking rock below the Regatta Box (containing labradorite and andesine felspar, augite, hornblende and quartz. Paul's detailed description leaves no doubt as to the correctness of this correlation. Comparison of their composition with that of essexite (Table 4, Analysis E) reveals their essential difference from this rock, despite a resemblance in some respects.

#### THE TRANSITION ZONE.

The relatively narrow transition zone that separates the zone of thermal alteration from the hybrid rocks proper is characterized by the breakdown of the original plagioclase, with the consequent destruction of the doleritic texture of the rocks. Thin sections (11) show that the plagioclase crystals become dissected by a network of narrow veins of alkali felspar which slowly widen, leaving isolated remnants of the plagioclase enclosed in the alkali felspar, until in the final stage, no plagioclase remains at all. The alkali felspar in these veins appears to be albite, because in one instance it showed a refractive index lower than that of the disintegrating plagioclase, but higher than that of the cloudy crystals of orthoclase surrounding the plagioclase. The albite is clear and untwinned.

This breakdown of the plagioclase is accompanied by a transformation of the hornblende to granular aggregates of colourless augite (Plate V., figs. 7 and 8). Assuming that the composition of the augite is similar to that of augite of similar appearance in the hybrid rocks proper, it contains much more lime (Table 6, Analysis No. 2) than the hornblende it replaces

(Table 6, Analysis No. 6). This lime is derived, presumably, from the breakdown of the plagioclase. Some evidence that this is so is provided by the occurrence of granules of augite in the albite veinlets between residual areas of plagioclase. The iron ore granules in the hornblende are unaffected by the change, so that much of the augite is at first filled with inclusions of iron ore (Plate V., fig. 8). As the augite grains coalesce, however, they clear themselves of such inclusions. Traces of primary pyroxene still remain in some sections, and grains of coarse magnetite, with rims of coarse biotite flakes, are still present.

Pyrite, apatite, orthoclase, and perhaps quartz, have been introduced into the rock, and occur in small veins. One such vein was observed cutting through a clot of small equi-granular crystals of hornblende, preserved from alteration by a fringe of granophyre.

Despite the reconstitution that the rock has undergone in this narrow transition zone, its bulk composition has changed very little. An analysis of a representative specimen (11) (Table 4, Analysis No. 4) shows a slight increase in soda and potash over the less altered dolerites, and some reduction in magnesia content, but is otherwise similar.

#### THE ZONE OF HYBRIDIZATION.

The hybrid rocks proper can be divided into two groups (excluding the dyke rocks that intersect them): (1) leucocratic rocks, poorer in CaO than the dolerite, but much richer in  $K_2O$ , and (2) melanocratic rocks, as rich or richer in CaO than the dolerite, and moderately rich in  $K_2O$ . This division is artificial, because there is a frequent gradation between the two types, which are irregularly distributed throughout the outcrops on the beach and in the cliff face. The grain size of the hybrid rocks is similar to that of the dolerites, but the texture is more granular, and the higher proportion of felspathic constituents makes even the most basic of the hybrid rocks appear greyer than the metamorphosed dolerite. In a number of specimens, particularly the more basic rocks, the feldspars (and feldspathoids) tend to occur as large poecilitic crystals (1–2 mm.) with numerous inclusions of the several ferromagnesian minerals. In some, the orthoclase tends to be porphyritic. The "phenocrysts" may enclose plagioclase residuals, but do not enclose ferromagnesian minerals.

The hybrid rocks all consist essentially of orthoclase and a lime-rich pyroxene, which is generally more or less altered to biotite and brown melanite garnet, together with areas of a lime zeolite, probably scolecite, notable amounts of magnetite, and coarse idiomorphic crystals of sphene and apatite. Some specimens, particularly the lime-rich ones, contain residual plagioclase, generally armoured about by broad zones of orthoclase, and some contain nepheline. The differences in chemical composition shown by these rocks (Table 5) arise largely from differences in the relative proportions of ferromagnesian minerals and orthoclase. The analyses show that  $K_2O$  is present in all these rocks in considerably greater amounts than in the dolerite, and there can be little doubt that most of this potash is introduced from the magma represented by the veins and schlieren of syenite-aplite and syenite-pegmatite that traverse the rocks, and in places appear to grade into them. The introduction of the potash appears to have rendered the rocks more or less fluid, and has led to local concentrations of the ferromagnesian minerals, which locally dominate the felspathic constituents. Occasionally the pyroxene crystals have segregated into clots 2 to 3 cm. in diameter. It is to be noted that the leucocratic rocks (Table 5, Analyses 1, 2) bear a close chemical resemblance to the hauyne-sanidine-garnet porphyries (Table 2) and related dyke rocks.

The pyroxene is a lime-rich variety (Table 6, Analysis 2), closely resembling the pyroxenes in the alkali-porphyrics (Table 6, Analysis 1). Presumably, addition of lime from the dolerite to the syenitic magma has led simply to an increased crystallization of augite. This pyroxene consists generally of a colourless core with a green marginal zone. In basal sections the green zone is strongly pleochroic from green to yellow, and has a small extinction angle, so that presumably it consists of aegirine. Such green rims appear to be lacking in the rocks of the transition zone, described above, and appear only in the hybrid rocks proper, in which the plagioclase has largely or completely disappeared. As indicated, the disappearance of the plagioclase is a process of solution in which the lime, soda and alumina of the plagioclase become separated. The lime reappears in the hybrid rocks partly as diopsidic pyroxene (the colourless cores of the pyroxene crystals), and partly as lime zeolite. In some specimens, the soda reappears as albite, and in others as nepheline, but much of it, presumably, enters into the later-forming pyroxene, to form rims of aegirine around the cores of diopsidic pyroxene. The common presence of albitic perthite in the sanidine crystals of the syenite-pegmatite veins suggests that some of the soda in the hybrid rocks was introduced along with the potash, and there is little to indicate what proportions of the soda were derived from these two possible sources. The alumina appears to have entered the magma, intensifying its tendency to become saturated in this respect.

In all but a few sections the pyroxene has reacted to some degree with the syenitic magma. The magnesia and some of the iron in the pyroxene have combined with the introduced potash to form a magnesia-rich biotite (Table 6, Analysis 7), while the lime and the remainder of the iron have combined to form a brown garnet whose composition is probably similar to that shown in Table 6, Analysis 8. This reaction has the effect of returning to the magma about 25% of the  $\text{SiO}_2$  originally incorporated in the augite. The biotite is pleochroic from a brownish or a greenish-yellow to almost black. Some crystals enclose irregular lighter coloured patches which suggest ghosts of pyroxene grains; others contain inclusions of apatite, and rarely of pyroxene. In some rocks, in which the alteration of the pyroxene is advanced, the biotite occurs as scattered plates 2 to 3 mm. across. The analysed biotite was a hand-picked sample of these coarse crystals.

The appearance of the garnets varies somewhat. In many sections they appear first as small blebs or granules. These tend to grow together into larger grains that show rudimentary crystal outlines. The larger grains contain inclusions of sphene, pyroxene, biotite, and occasionally orthoclase. With increasing size, the crystals develop zoning, a lighter brown core passing into a darker or clove-brown margin.

The progress of this reaction of the pyroxene with the potassic magma to form garnet and biotite varies even within a single thin section. In some sections, almost every grain of pyroxene is rimmed with a fine-grained intergrowth of garnet and biotite (Plate V., fig. 9); in others, the pyroxene crystals are more or less completely altered to an intergrown garnet and biotite (Plate V., figs. 10, 11). In others, some grains of pyroxene have reacted, while adjacent crystals appear unaffected. In a number of sections, the reaction is much more pronounced where the pyroxene crystals are in contact with orthoclase grains than where they are embedded in patches of zeolite, but this is not invariably so. In the coarser-grained rocks the biotite and garnet tend to separate and form relatively large individual crystals (Plate V., fig. 12), but in the finer-grained rocks they are often intimately intergrown. In some sections the amount of garnet and biotite

exceeds that of pyroxene, but generally the relative proportions of the three minerals vary greatly from place to place in a single section. Only occasionally has the pyroxene been completely replaced or nearly so, but this is the case in some of the more potash-rich rocks.

The pyroxene is characteristically associated with a zeolitic mineral that occurs as irregular areas and narrow veins up to 1.0 mm. wide. The zeolite consists of fibrous rosettes, which when they are well grown and are not weathered, are anisotropic, with low polarization colours (Plate IV., fig. 3). Frequently, however, they show only vague anisotropism, and many patches, which are cloudy in ordinary light, appear isotropic, so that there may be more than one variety of zeolite present. The anisotropic mineral, scraped from a veinlet, has a refractive index between 1.515 and 1.520, and gives a strong positive microchemical test for calcium. The zeolites with a refractive index of this order are the lime-soda zeolite thompsonite, and the lime-zeolites scolecite and laumontite. The low birefringence best fits scolecite. Previous investigators have regarded this mineral as natrolite, pseudo-morphous after nepheline. It is to be noted, however, that the zeolite is most abundantly developed in rocks which, while they contain distinctly more potash than the dolerites, contain if anything, less soda. The soda in the analyses can be accounted for largely by the aegirine rims of the pyroxene crystals, which would leave altogether too little soda for the zeolite to be natrolite. The zeolite occurs in greatest abundance in the lime-rich rocks, and is present only in small amounts, or is absent in rocks rich in potash and relatively poor in lime. Moreover, in the lime-rich rocks the lime content equals or exceeds that of the dolerite, and it seems unlikely that there is sufficient pyroxene present in them to account for the whole of the lime. It is concluded, therefore, that the zeolite is a lime-rich variety, the lime being derived from the breakdown of plagioclase from the original dolerite. As confirmation of this, one section contains residual plagioclase, more or less protected by rims of orthoclase, in which the plagioclase appears to show all stages of gradation into the zeolitic substance.

The veinlets of zeolite are of late formation, since in some sections they cut across large orthoclase crystals, displacing the two halves (Plate IV., fig. 3). In other sections the zeolite veinlets cut through garnet-biotite clots, while frequently the zeolite fills the interstices between orthoclase crystals. The more basic specimens (18) (Table 5, Analysis 4) contain a proportion of coarse grains of fresh nepheline, up to 0.3 mm. across. The nepheline, like the orthoclase, encloses numerous smaller crystals of pyroxene, garnet, and biotite. It can be distinguished from the orthoclase only by its uniaxial figure and its negative character, so that it is easily overlooked. Paul (1906) analysed a still more basic rock (Table 5, Analysis A) in which nepheline was apparently more abundant and biotite was present as occasional large crystals. This rock is reported to have occurred as scattered stones, not in situ, between the Regatta Box and the Point. Rosenbusch referred to it as a mica-nephelinite "with the habit of a monchiquite" (Twelvetrees, 1902) and Paul (1906) called it a "monchiquitic nephelinite" with shonkinitic affinities. Twelvetrees (1907) later classed it as a monchiquitic shonkinite. Its general resemblance to shonkinite in chemical composition may be seen by comparing Analyses A, B and C in Table 5, but it is more basic than typical shonkinite.

The rock described as jacupirangite (Twelvetrees, 1902A) appears to be an even more basic variety, from which orthoclase was excluded. It consisted essentially of nepheline, augite, sphene, garnet, apatite, magnetite and biotite. A careful search was made for this rock, without success,



and it is certain that it must be of very restricted occurrence—no more than a localized segregation—though Twelvetrees' (1902A) description would lead one to think otherwise.

The feldspar in these rocks is chiefly orthoclase. In some sections it tends to be porphyritic, with lath or platy phenocrysts from 1 to 3 mm. long in a finer-grained groundmass of lath-like orthoclase grains about 0.1 mm. long. In other sections, the orthoclase forms equigranular plates, 1 to 2 mm. across. The individual crystals commonly enclose grains of iron ore, garnet, biotite and pyroxene.

In the more leucocratic rocks (16), the orthoclase plates tend to be sub-parallel, as in the syenite-pegmatites, and are about 2.0 mm. x 0.2 mm., with smaller prisms of pyroxene, or in some cases hornblende, interleaved with them. The coarser crystals contain a little micropertthitic albite in some sections.

Remnants of plagioclase are preserved in some of the more lime-rich rocks (21, 24). The plagioclase occurs as zoned cores to orthoclase crystals, and is traversed by fractures that do not extend into the surrounding orthoclase, so that frequently the plagioclase inclusions are ragged remnants (Plate IV., fig. 4). The plagioclase has a refractive index well above that of the orthoclase, and is optically positive, so that it is probably andesine.

Some sections (24, 29) contain a mineral that somewhat resembles altered plagioclase. It is biaxial and optically positive, with a refractive index about that of andesine, and a birefringence less than that of orthoclase. It tends to occur in more or less rectangular grains, with a prominent cleavage at right angles to the longer axis, and consistently extinguishes parallel to this cleavage. It commonly appears "dusty", and many grains are more or less altered to a zeolitic substance, the alteration developing along the cleavage. The low birefringence and the straight extinction do not fit andesine, and there is no orthorhombic mineral that has all the requisite optical characters, so that the mineral remains indeterminate. The untreated mineral is not affected by water-soluble dyes like methylene blue, though the straw-coloured biotite in one section (29) was rendered reddish-violet by immersion in an aqueous solution of this dye.

The sphene in the hybrid rocks occurs as coarse crystals, up to 2 mm. long. Occasionally clots of as many as fifty crystals of sphene, the individual crystals being about 0.5 mm. long, have been observed, the clots of sphene forming the cores of clots of pyroxene crystals. Small crystals of sphene are included in some of the garnet grains, and sphene is often intimately associated with areas of intergrown biotite and garnet, suggesting that it represents titania set free during the transformation of the pyroxene into these minerals.

It may be noted that although sphene occurs in many of the alkali rocks, the amount of  $TiO_2$  in the analyses of these rocks rarely exceeds 0.5%. This is true also of the potash-rich hybrid rocks. In the lime-rich hybrids, however, and in the dolerite, the  $TiO_2$  content is commonly in excess of 1.0%, suggesting that the sphene in the lime-rich rocks comes largely from the ferromagnesian of the original dolerite.

The apatite tends to form equally coarse-grained crystals, some of which are speckled with black dust-like inclusions. Most of it, however, is clear and colourless. It is most abundant in the lime-rich hybrid rocks, which contain in excess of 1.0%  $P_2O_5$ , as compared with less than 0.5% in most of the potash-rich hybrid and dyke rocks, and the dolerite. The magnetite in the hybrid rocks occurs as equi-dimensional grains whose size corresponds to the general grain size of the particular specimen. It tends to associate with the biotite-garnet intergrowths, and does not occur as inclusions in the pyroxene.

### Conclusions.

The metamorphic alteration of the dolerite at Regatta Point provides an excellent example of the distinctive behaviour of igneous rocks when subjected to thermal metamorphism, as outlined by Harker (1932, pp 103-110). The first stage is the conversion of a higher mineral (pyroxene) to a lower (hornblende). The dolerite, having cooled rapidly from a high temperature, its pyroxene minerals are in a metastable state. The first effect of slowly rising temperature has been to restore molecular mobility to the rock, and permit these metastable, high temperature minerals to react with their matrix, and transform to hornblende, a mineral stable at the lower temperature induced by the thermal metamorphism. Similarly, the magnetite has reacted to form biotite, whereas the feldspar, as is common to such rocks, has proved more stable, and has not recrystallized appreciably. In this initial stage of metamorphism, the minerals have, therefore, undergone the reaction changes that they would normally have undergone if the dolerite magma had cooled slowly. It is "a suspended reaction, which now takes effect when the appropriate temperature is realized".

With advancing metamorphism (in the "transition zone"), this change is reversed. At the higher temperatures now prevailing, augite and not hornblende is the stable mineral.

At this stage, however, reaction with the invading potash-rich magma assumes significant proportions, with the development of hybrid rocks, and the reactions involved provide an illustration of Bowen's (1928, pp. 197-200) conclusions as regards the processes of assimilation and hybridization.

Bowen states (p. 197) that "any magma saturated with a certain member of a reaction series, is effectively supersaturated with all higher members of that reaction series. It cannot . . . dissolve inclusions of such higher members, but can only react with them to convert them into that member of the reaction series with which it is saturated." Thus we find the potash-rich magma, which is saturated with soda-rich sanidine feldspar, reacting with the plagioclase of the dolerite. The soda from the plagioclase can enter the syenitic magma, but the lime from the plagioclase can enter into the sanidine only in small amount, for the magma is saturated with respect to lime minerals. The excess lime is precipitated as augite, the lime mineral with which the syenitic magma is saturated. The effect is, therefore, simply to promote the normal process of crystallization. It may be noted that the process is somewhat more complicated than is indicated by Bowen's statement quoted above and involves the transference of the lime from one reaction series (the feldspars) to another (the ferromagnesian). The soda from the plagioclase is partly taken up by the later feldspars, and partly transferred to the pyroxenes. Where there has been local precipitation of pyroxene to excess, the residual magma appears to have been "desilicated", and the soda has been reprecipitated partly as nepheline. The alumina from the plagioclase is largely added to the magma, intensifying its tendency to become saturated in this direction.

Where the included rock contains minerals later in the reaction series than the minerals with which the magma is saturated, Bowen (p. 200) considers that the included minerals will simply dissolve, with a simultaneous precipitation of the minerals with which the magma is saturated. The hornblende of the metamorphosed dolerite, which is later in the ferromagnesian reaction than the augite of the syenitic magma, was thus under a double compulsion to give place to augite. Increasing intensity of thermal metamorphism drove it in this direction, while the incoming

syenitic magma tended to dissolve it, when its constituents were reprecipitated as augite. It is not surprising, therefore, that the passage from the metamorphosed dolerite zone to the hybrid zone is one of rapid transition, with no sharp margin. Similarly, the late reaction of augite to form garnet and biotite as the magma became increasingly saturated in  $Al_2O_3$  is only a repetition on a more pronounced scale of a reaction normal to the (apparently) uncontaminated syenitic magma.

These changes bear out Bowen's further conclusion (Bowen, 1928, p. 223) that "magmas may incorporate considerable quantities of foreign inclusions, both by the methods of reactive solution and by reactive precipitation. All of these actions are, however, an emphasizing of normal processes possible in the absence of foreign matter". This conclusion has significance in any speculation as to the nature of the deeper-lying unexposed alkali rocks at Port Cygnet.

It is established that the intrusion is a differentiated syenitic stock of which the uppermost zone is presumably, from its texture, a chilled margin. This marginal zone of syenite porphyry closely resembles in chemical composition the banatite that forms the upper part of the Mt. Dromedary laccolith in New South Wales. The Mt. Dromedary laccolith appears to have developed through the differentiation in situ of a monzonitic magma, giving rise to an uppermost zone of banatite, and lower zones of shonkinite and pyroxenite (approaching jacupirangite).

Assuming that assimilation only emphasises normal processes, then the local development of a hybrid rock approximating to a shonkinite at Regatta Point, suggests that the trend in the differentiation of the Port Cygnet stock would have been towards the formation of a layer of shonkinite within the stock, in addition to the visible upper layer of syenite-porphyry resembling banatite. Analogy with Mt. Dromedary suggests that these rock types are derived from the differentiation of a monzonitic magma.

The process of differentiation, as at Mt. Dromedary, involved a concentration of potash, in the form of large phenocrysts of sanidine, presumably by upward displacement of residual potash enriched magma, and possibly by upward flotation of the early-formed sanidine crystals. The sanidine crystallized side by side with plagioclase feldspars rich in soda, the two series becoming increasingly incapable of solid solution with one another as the temperature decreased. Pronounced fractional crystallization of the sanidine aided the concentration of potash in the residual magma. The early formed sanidine crystallized at a temperature which permitted a high degree of solid solution of albite in the sanidine, and became armoured about by marginal zones progressively richer in potash which effectively prevented return of soda to the magma as the temperature declined. The soda-rich cores became increasingly unstable as the temperature declined and finally unmixed to form micropertthite.

In the later stages of differentiation, when considerable crystallization of coarse sanidine crystals had occurred, it seems possible that the intrusion of some of the dykes was accompanied by some degree of filter press action. This would explain the occurrence of dykes with identical matrices having very variable proportions of sanidine phenocrysts, like the tinguaites, and especially the syenite aplites and pegmatites.

The close chemical resemblance of the leucocratic hybrid rocks at Regatta Point to the more potassic dyke rocks suggests that the dyke rocks are representative of a zone or layer of differentiated rock within the intrusion.

The hauyne in the dyke rocks is presumably the equivalent of the nepheline in some of the hybrid rocks.

TABLE 1.—ANALYSIS OF THE SYENITE PORPHYRY (BANATITE).

	1.	2.	A.	B.	C.
SiO <sub>2</sub> .. .. .	61·25	63·10	64·49	61·96	66·64
Al <sub>2</sub> O <sub>3</sub> .. .. .	18·59	17·11	17·48	17·07	15·57
Fe <sub>2</sub> O <sub>3</sub> .. .. .	1·58	1·04	1·64	2·35	1·91
FeO .. .. .	2·18	3·02	1·69	3·37	1·94
MgO .. .. .	0·58	1·15	0·66	1·38	1·41
CaO .. .. .	4·05	3·65	3·28	3·41	3·50
Na <sub>2</sub> O .. .. .	4·30	3·94	4·16	4·65	3·41
K <sub>2</sub> O .. .. .	4·06	4·64	4·79	3·80	3·72
H <sub>2</sub> O + 110 .. .. .	0·42	0·42	0·52	0·93	1·15
H <sub>2</sub> O - 110 .. .. .	0·60	0·55	0·18		
CO <sub>2</sub> .. .. .	Nil	0·24	0·71		
TiO <sub>2</sub> .. .. .	1·28	0·82	0·46	0·99	0·50
P <sub>2</sub> O <sub>5</sub> .. .. .	0·61	0·30	0·22		0·19
MnO .. .. .	0·42	0·12	0·11	0·09	0·06
	99·92	100·10	100·39	100·00	100·00

1. Syenite-porphry (No. 54), containing hornblende and pyroxene, from near the saddle of the road from Lymington to Wattle Grove, Port Cygnet district; *Analyst*: A. B. EDWARDS.
2. Syenite-porphry (No. 72), with altered hornblende, from Petchey's Bay, Port Cygnet district; *Analyst*: A. B. EDWARDS.
- A. Banatite (Syenite), Mt. Dromedary laccolith, N.S.W. (I. A. Brown, *Proc. Linn. Soc. N.S.W.*, vol. 55, Pt. 5, p. 637, 1930).
- B. Average Akerite (R. A. Daly, *Igneous Rocks and the Depths of the Earth*, p. 12).
- C. Average Quartz Monzonite (R. A. Daly, *Ibid.*, p. 15).

For location of analysed specimens, see Fig. 2.

TABLE 2.—ANALYSES OF PORT CYGNET DYKE ROCKS.  
(Analyst: A. B. Edwards.)

	1.	2.	A.	B.	3.	4.	C.	D.	E.	5.	6.
SiO <sub>2</sub> .. .. .	58·50	54·70	55·00	55·87	57·75	54·20	55·02	57·46	62·70	61·20	62·20
Al <sub>2</sub> O <sub>3</sub> .. .. .	19·81	19·15	20·91	18·21	18·80	20·48	20·42	15·40	16·40	21·90	18·09
Fe <sub>2</sub> O <sub>3</sub> .. .. .	1·71	3·65	2·05	..	6·05	4·90	3·06	4·87	3·34	1·77	0·72
FeO .. .. .	1·66	1·58	3·73	8·01	0·84	1·26	1·82	0·87	2·35	0·57	1·15
MgO .. .. .	0·47	0·69	0·63	0·46	1·01	0·40	0·59	1·37	0·79	0·60	0·53
CaO .. .. .	5·65	5·55	3·22	4·54	2·35	2·85	1·67	2·59	0·95	1·00	3·60
Na <sub>2</sub> O .. .. .	3·95	4·57	2·80	3·36	3·33	4·03	8·63	5·48	7·13	2·20	2·83
K <sub>2</sub> O .. .. .	7·57	7·02	8·66	5·75	9·02	9·39	5·38	9·44	5·25	9·90	8·97
H <sub>2</sub> O + 110° C. .. .. .	0·11	0·65	1·87	2·28	0·28	0·42	2·77	0·82	0·70	0·25	0·52
H <sub>2</sub> O - 110° C. .. .. .	0·15	0·38		0·42	0·85	0·09		0·65		0·35	
CO <sub>2</sub> .. .. .	Nil	Nil	0·38	..	Nil	Nil	0·13	..	Nil	Nil	Nil
TiO <sub>2</sub> .. .. .	0·32	0·45	0·35	..	0·10	0·20	0·31	0·60	0·92	tr.	0·16
P <sub>2</sub> O <sub>5</sub> .. .. .	0·30	0·24	tr.	..	tr.	0·50	0·04	0·21	..	tr.	0·99
MnO .. .. .	0·12	0·21	0·77	2·61	0·25	0·12	0·18	tr.	tr.	tr.	0·06
	100·32	99·44	101·03*	101·09	100·20	99·40	100·00	100·42*	100·53	100·04	100·17

\* + 0·61 S.

\* + &c., 1·19.

1. Hauyne-sanidine-garnet-porphry (81), quarry near road leading from Regatta Point to Wattle Grove.
2. Hauyne-sanidine-garnet-porphry (110), from road north of Toby's Hill.
- A. "Garnet-mica-solvsbergite", from vicinity of Regatta Point (F. P. Paul, *Tscher. Min. Petr. Mitt.*, vol. 25, n.f., 269-318, 1906).
- B. "Garnet-trachyte", on beach between Port Cygnet and Lymington (W. A. McLeod and O. E. White, *Papers Roy. Soc. Tas.*, 1898-99, p. 75).
3. Sanidine-tinguaite (93), north of jetty, northern headland of Copper Alley.
4. Tinguaitite (95), Mt. Mary mine, Mt. Mary.
- C. Average tinguaite (R. A. Daly, *Igneous Rocks and the Depths of the Earth*, p. 27, 1933).
- D. Tinguaitite with sanidine phenocrysts, Bearpass Mts., Montana (Weed and Pirsson, *Am. Jour. Sci.*, II, p. 192, 1896).
- E. Solvsbergite, Longthol, Norway. (Brogger, *Eruptivgesteine Krist.*, I., p. 80, 1894.)
5. Syenite-pegmatite (25), inlet south of Regatta Point.
6. Garnet-orthoclasite (19), Regatta Point.

For location of analysed specimens, see Fig. 2.

TABLE 3.—COMPOSITION OF SANIDINE PHENOCRYSTS IN PORT CYGNET ROCKS.  
(Analyst: A. B. Edwards.)

Rock.	K <sub>2</sub> O.	Na <sub>2</sub> O.	Calculated Composition.	Mean Refractive Index.
Syenite-porphry (banatite) (54, 72) .. ..	5·47	4·37	Or33Ab37An30	1·525 ± ·003
Sanidine tingualte (93) .. ..	9·50	3·51	Or57Ab29An14	1·525 ± ·003
Hauyne-sanidine-garnet-porphry (110), (magple-rock)	9·66	3·09	Or58Ab26An16	1·525 ± ·003
Hauyne-sanidine-garnet-porphry (116), Living-stone Hill	9·95	3·14	Or59Ab27An14	1·525 ± ·003
Sanidine-garnet-porphry (66), (biscuit-rock) ..	12·69	1·84	Or78Ab16An6	1·525 ± ·003

TABLE 4.—ANALYSES OF METAMORPHOSED DOLERITE AT REGATTA POINT, PORT CYGNET.  
(Analyst: A. B. Edwards.)

—	1.	2.	3.	4.	5.	A.	B.	C.	D.	E.
SiO <sub>2</sub> ..	54·90	54·50	55·20	55·20	55·20	52·65	55·70	38·30	38·38	48·64
Al <sub>2</sub> O <sub>3</sub> ..	13·49	14·01	14·88	15·00	17·26	16·23	17·53	7·05	6·15	17·96
Fe <sub>2</sub> O <sub>3</sub> ..	4·40	3·51	3·68	4·24	4·23	0·51	0·23	9·07	11·70	4·31
FeO ..	6·12	6·89	7·49	5·11	5·90	8·21	9·21	6·17	8·14	5·58
MgO ..	5·70	5·10	4·27	4·15	4·76	6·64	2·79	11·58	11·47	4·00
CaO ..	9·65	9·55	9·75	9·35	8·20	11·34	9·50	19·01	18·60	8·89
Na <sub>2</sub> O ..	2·53	1·90	2·22	2·95	1·94	1·58	2·29	0·74	0·78	4·30
K <sub>2</sub> O ..	1·60	1·54	0·99	2·00	1·20	0·90	1·33	0·75	0·13	2·28
H <sub>2</sub> O + 110 ..	0·18	0·55	0·55	0·21	0·15	0·48	0·12	0·33	0·54	} 1·34
H <sub>2</sub> O - 110 ..	0·42	0·37	0·12	0·35	0·15	0·85	0·56	0·14	0·18	
CO <sub>2</sub> ..	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·32	Nil	..
TiO <sub>2</sub> ..	0·88	1·35	1·25	1·36	1·32	0·58	0·85	4·94	4·32	1·86
P <sub>2</sub> O <sub>5</sub> ..	0·12	0·20	0·06	0·10	0·12	0·01	tr.	0·82	0·17	0·65
MnO ..	0·21	0·17	0·16	0·17	0·15	0·15	0·12	0·32	0·16	0·19
	100·20	99·64	100·62	100·19	100·58	100·13	100·23	*99·89	100·72	100·00

\* + &amp;c., 0·06.

1. Slightly metamorphosed dolerite (36), just south of Cygnet jetty, Regatta Point.

2. Partly unalitized dolerite (1a), midway between Cygnet jetty and Regatta Point.

3. Completely unalitized dolerite (7A), north side of Regatta Point.

4. Metamorphosed dolerite (11) from the transition zone, Regatta Point.

5. Dolerite dyke (40), south side of Copper Alley, Port Cygnet.

A. Average undifferentiated Mesozoic dolerite of Tasmania (average of 6 analyses). (Edwards, *Jour. Geol.* 50, p. 465, 1942.)B. Differentiated dolerite from 950 feet above sea level, Mt. Nelson, Tasmania. (Edwards, *Ibid.*, p. 470.)C. Jacupirangite, Magnet Cove (Washington, *Jour. Geol.* 9, 1901, 620-22).D. Jacupirangite, Sao Paulo, Brazil. (Washington, *Ibid.*)E. Average Essexite. (Daly, *Igneous Rocks and the Depths of the Earth*, 1933, p. 22.)

For location of analysed specimen, see Fig. 4 and Fig. 2.

TABLE 5.—ANALYSES OF ALKALI HYBRID ROCKS AT REGATTA POINT, PORT CYGNET.  
(Analyst: A. B. Edwards.)

—	1.	2.	3.	4.	A.	B.	C.
SiO <sub>2</sub> ..	55·90	56·10	49·10	49·85	46·30	48·34	48·66
Al <sub>2</sub> O <sub>3</sub> ..	19·08	17·37	16·70	8·35	9·87	11·79	12·36
Fe <sub>2</sub> O <sub>3</sub> ..	2·78	3·80	4·60	10·96	7·43	2·31	3·08
FeO ..	2·88	2·16	5·04	4·75	5·40	7·72	5·86
MgO ..	1·59	1·32	2·52	5·56	7·18	9·59	8·09
CaO ..	5·85	5·65	9·25	9·25	14·26	12·76	10·46
Na <sub>2</sub> O ..	0·71	2·30	1·90	1·84	1·74	1·60	2·71
K <sub>2</sub> O ..	9·29	8·87	6·61	5·42	3·81	3·17	5·15
H <sub>2</sub> O + 110° C. ..	0·32	0·23	0·52	0·65	} 1·85	0·68	} 1·46
H <sub>2</sub> O - 110° C. ..	0·30	0·43	0·38	0·42		0·04	
CO <sub>2</sub> ..	Nil	Nil	Nil	Nil	n.d.	pr.	..
TiO <sub>2</sub> ..	0·48	1·17	1·44	1·08	1·37	0·88	0·97
P <sub>2</sub> O <sub>5</sub> ..	0·20	0·10	1·43	1·27	1·01	0·87	1·07
MnO ..	0·36	0·11	0·21	0·26	tr.	0·15	0·13
	99·74	99·61	99·67	99·66	100·22	99·90	100·00

1. Leucoeratic hybrid rock (27), or contaminated syenite, about 300 yards south of the transition zone (Judge's Box).

2. Leucoeratic hybrid rock (14), about 70 yards south of the transition zone (Judge's Box).

3. Melanocratic hybrid rock (24), near the head of the inlet on the south side of Regatta Point, about 250 yards south of the transition zone (Judge's Box).
4. Melanocratic hybrid rock (18), about 150 yards south of the transition zone (Judge's Box).
- A. "Monchiquitic-nephelinite" (F. P. Paul, *Tscher. Minn. Petr. Mitt.*, 25, n.f., 269-318, 1906). This is the "monchiquitic shonkinite" of Twelvetrees.
- B. Shonkinite, Tilba Tilba Village, Mt. Dromedary, New South Wales. (I. A. Brown, *Proc. Linn. Soc. N.S.W.*, 55 (5), 656, 1930.)
- C. Average shonkinite. (Daly, *Igneous Rocks and the Depths of the Earth*, 1933, p. 23.)
- For location of analysed specimens, see Fig. 4.

TABLE 6.—ANALYSES OF FERROMAGNESIAN MINERALS IN PORT CYGNET ROCKS.

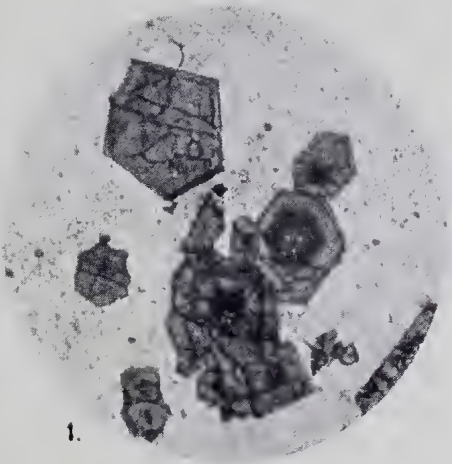
(Analyst: A. B. Edwards.)

	Pyroxenes.				Hornblendes.			Biotite.	Garnet.	
	1.	2.	3.	A.	4.	5.	6.	7.	8.	B.
SiO <sub>2</sub>	45.18	48.30	48.72	48.40	39.50	39.20	48.40	34.2	36.00	36.87
Al <sub>2</sub> O <sub>3</sub>	6.02	5.14	6.40	5.25	17.45	16.06	12.74	5.9	7.98	7.28
Fe <sub>2</sub> O <sub>3</sub>	9.15	7.52	4.75	2.49	9.60	11.42	8.80	10.2	17.07	..
FeO	6.77	6.55	14.40	15.05	11.52	8.80	12.24	13.8	4.17	17.12
MgO	8.00	10.16	10.93	14.88	7.60	3.76	6.30	16.0	0.34	12.49
CaO	23.25	20.70	13.13	12.70	12.20	15.50	10.90	Nil	28.80	11.98
Na <sub>2</sub> O	n.d.	n.d.	n.d.	0.10	n.d.	1.33	n.d.	0.9	n.d.	..
K <sub>2</sub> O	n.d.	n.d.	n.d.	0.05	n.d.	1.82	n.d.	10.0	n.d.	..
H <sub>2</sub> O	n.d.	n.d.	n.d.	0.20	n.d.	n.d.	n.d.	n.d.	n.d.	0.29
TiO <sub>2</sub>	1.06	0.44	0.60	0.31	0.25	1.39	1.25	1.3	1.76	..
P <sub>2</sub> O <sub>5</sub>	Nil	0.02	tr.	tr.	0.15	0.61	0.12	0.5	0.72	..
MnO	0.91	0.18	0.09	0.35	0.15	0.72	0.09	tr.	1.24	13.68
	100.34	99.01	99.02	99.60	98.42	100.60	98.84	92.8	98.08	99.71

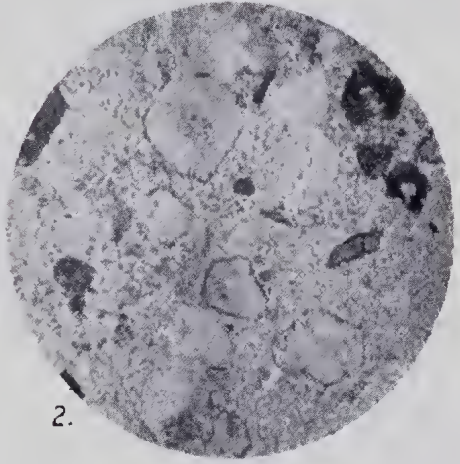
1. Pyroxene (augite) from syenite-porphry dyke, Deep Bay.
2. Pyroxene (augite) from hybrid rock (18), Regatta Point.
3. Composite pyroxene, slightly uralitized, from the dolerite (36), Regatta Point.
- A. Composite pyroxene, chilled base of Mt. Wellington dolerite sill (Edwards, *Jour. Geol.*, vol. 50, p. 583, 1942).
4. Hornblende, from syenite-porphry (banatite) dyke, Little Oyster Cove.
5. Hornblende, from haayne-sanidine-garnet-porphry dyke (110), Toby's Hill, Port Cygnet.
6. Hornblende, from uralitized dolerite (7), Regatta Point.
7. Biotite, from leucocratic hybrid, or contaminated syenite (30), Regatta Point.
8. Andradite-Garnet (melanite), from haayne-sanidine-garnet-porphry (110), Toby's Hill, Port Cygnet.
- B. "Johnstonite" garnet, from 'garnet-trachyte' (haayne-sanidine-garnet-porphry), from Copper Alley jetty (White and McLeod) Papers *Roy. Soc. Tas.*, 1899, p. 75).

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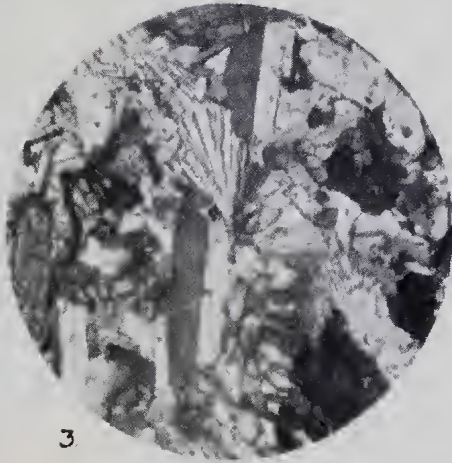
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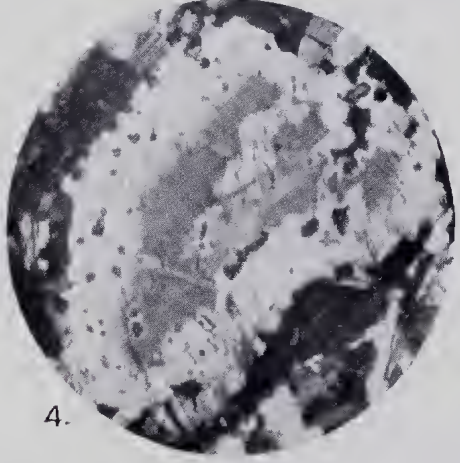
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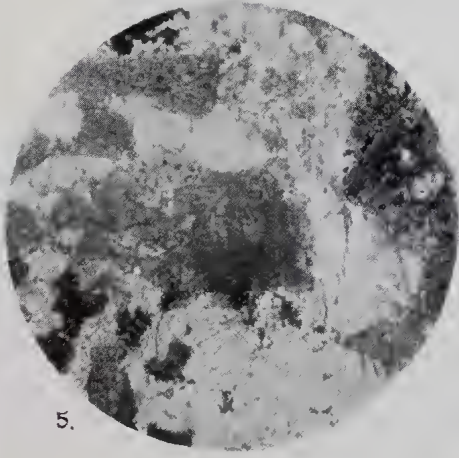
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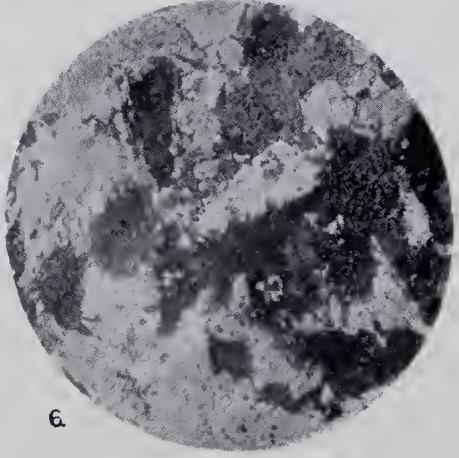
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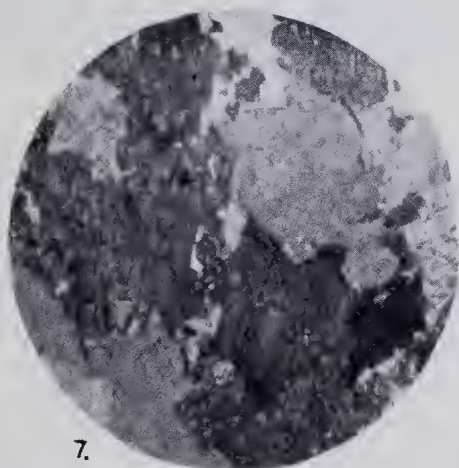
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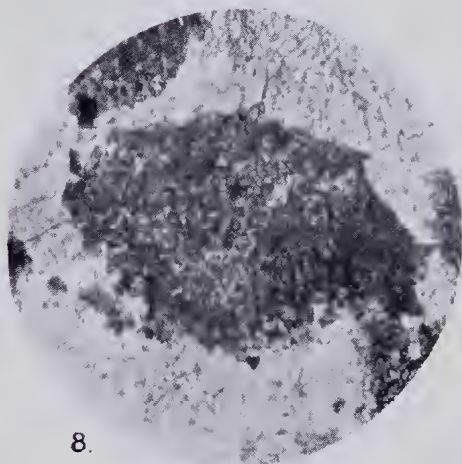
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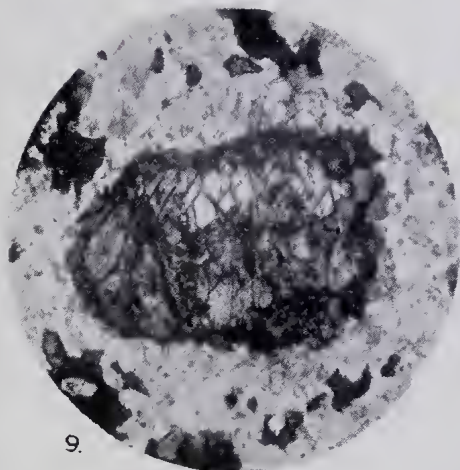




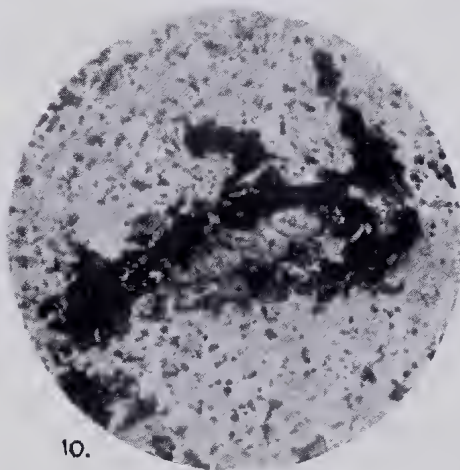
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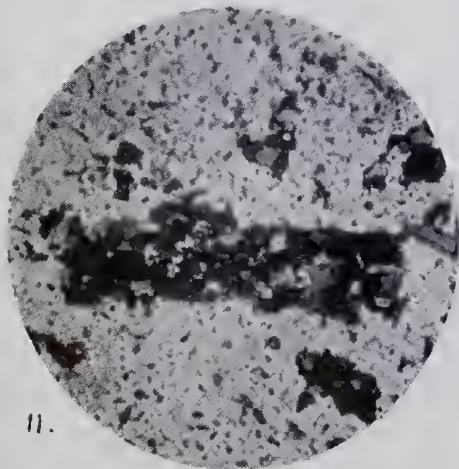
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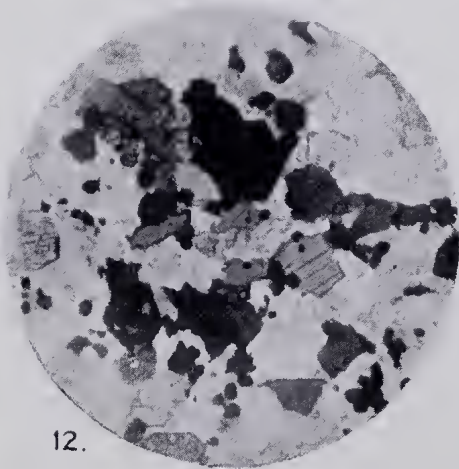
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## Illustrations.

### PLATE IV.

- FIG. 1.—Cluster of zoned melanite garnet in hauyne sanidine-garnet-porphry dyke (110), Toby's Hill. Ordinary light.  $\times 25$ .
- FIG. 2.—Group of altered hauyne crystals showing their characteristic form. Hauyne-sanidine-garnet-porphry (81) near Regatta Point. Ordinary light.  $\times 35$ .
- FIG. 3.—Zeolite vein cutting and displacing a plate of sanidine in hybrid rock, Regatta Point. Nicols crossed.  $\times 35$ .
- FIG. 4.—"Phenocryst" of orthoclase enclosing remnants of a large plagioclase crystal (dark), in hybrid rock (24), Regatta Point. Nicols crossed.  $\times 25$ .
- FIG. 5.—Least altered dolerite (36) showing characteristic texture of intergrown plagioclase and pyroxene. Near Cygnet jetty. Ordinary light.  $\times 35$ .
- FIG. 6.—Thermally metamorphosed dolerite (7A) with pyroxene converted to hornblende, but preserving the texture of the dolerite. Regatta Point. Ordinary light.  $\times 35$ .

### PLATE V.

- FIG. 7.—Hornblende altering to granular augite, in dolerite from the transition zone. Regatta Point. Ordinary light.  $\times 45$ .
- FIG. 8.—Crystal of hornblende completely altered to granular augite and magnetite, in dolerite in the transition zone. Regatta Point. Ordinary light.  $\times 45$ .
- FIG. 9.—Pyroxene crystal with a narrow rim of biotite and melanite garnet, intergrown with one another. Hybrid rock, Regatta Point. Ordinary light.  $\times 40$ .
- FIG. 10.—Advanced stage of alteration of pyroxene (core) to biotite and garnet (margin). Ordinary light.  $\times 35$ .
- FIG. 11.—Pseudomorph of biotite and melanite garnet after pyroxene crystal. Ordinary light.  $\times 35$ .
- FIG. 12.—Hybrid rock with relatively coarse crystals of biotite and melanite garnet dispersed through it. Ordinary light.  $\times 30$ .